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Ecosystem services

for watershed management and planning

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“Don't be satisfied with stories, how things have gone with others. Unfold your own myth.”

Rumi, The Essential Rumi

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Summary

Human wellbeing in cities, often associated to availability of engineered structures, is increasingly linked to the conservation of ecosystems. This is the case of the urban water sector where the focus is shifting from adequate infrastructural arrangements to the key role of ecosystem services, thus offering a unique opportunity to achieve sustainability transitions. The urban water sector entails significant complexities and uncertainties, which no longer can be addressed effectively with traditional approaches. A new paradigm of "adaptation and integration", emerging as a collective effort of stakeholders that engage themselves in a process of social learning, is needed. However, real-life implementation is arduous: it requires linking diverse stakeholders and knowledge systems, across management levels and institutional boundaries. Three innovative concepts can help face this challenge, namely, ecosystem services, boundary work and learning organizations. Ecosystem services provide a holistic approach for framing socio-ecological issues and for integrating different biophysical and socio-economic data. Boundary work, i.e. the effort put in place to facilitate transfer of knowledge into action, informs active management of the tension at the interface between stakeholders that have differing views on what constitutes relevant knowledge. A learning organization is one that is skilled at creating and acquiring knowledge and modifying its behavior to reflect new insights. In this study, these three concepts are jointly explored to build operative approaches to support the implementation of adaptive management. To this end, the work is driven by four specific objectives presented hereafter.

The first objective is to frame the urban water sector form an ecosystem services perspective, synthesizing the most relevant aspects related to the exchange of water between watershed and city, and within the city. The proposed framework highlights the role of urban water sector in (i) linking ecosystem service production and benefit areas, (ii) bridging spatial scales ranging from the watershed to the household level and (iii) adopting ecosystem service-based responses to drivers of water vulnerability.

The second objective is to explore practices of boundary work in adaptive watershed management. Thus, an empirical investigation of how boundary work can facilitate knowledge co-generation and cooperative application in a case study of adaptive management in the Fuhrberg watershed (Germany) is conducted. The results suggest that scientific insights have been crucial for "enlightenment", "decision-support", and in "negotiations" between a water utility and stakeholders in Fuhrberg watershed management. The successful implementation of adaptive watershed management is attributed to boundary

work deployed by the water utility and ultimately to its high institutional capacity. This study, which is one of the first empirical assessments of boundary work in practice, presents many promising approaches for initiating boundary work in the case of water utilities. Yet, more comparative research is required to understand the influence of contextual differences on appropriate methods and potential outcomes of boundary work.

The third objective is to build and test an approach for designing and assessing impact of watershed investments, aiming to implement adaptive management. The proposed approach is structured to facilitate negotiations among stakeholders. Its strategic component includes setting the agenda, defining investment scenarios, and assessing the performance of watershed investments. Its technical component consists of tailoring spatially explicit ecosystem service models, generating future land use scenarios, and modeling impacts on ecosystem services. The approach is applied to a case study in a data-scarce context: Toker Watershed (Eritrea), considering soil erosion -related challenges. It produced spatially explicit data, which has been aggregated to assess quantitatively the performance of watershed investments, in terms of changes in selected ecosystem services, thus answering key management and planning questions. By addressing stakeholders' concerns of credibility, saliency, and legitimacy, the approach is expected to facilitate negotiation of objectives, definition of scenarios, and assessment of watershed investments.

The fourth objective is to explore water utilities as learning organization implementing adaptive watershed management. A conceptual framework for evaluating the institutional capacity of water utilities is used to characterize the water utilities in Hanover and Asmara. In particular, the institutional capacity of the "Hannover Water Utility" and "Asmara Water Supply Department" is investigated based on the available information from documents, literature and the previous results, and an interview with a key informant. The results show that the institutional capacity of Hanover Water Utility can be classified as Level 5 – "Progressive water utility" and Asmara Water Supply Department can be classified as Level 2 – "Basic water utility". An empirical pathway to test the results, by involving senior managers and informed scientists from both case studies, is proposed. In any case, the preliminary results highlight the attributes that determine the capacity of water utilities to become a central actor in the in the implementation of an adaptive watershed management.

This research, by jointly exploring the innovative concepts of ecosystem services, boundary work and learning organizations, builds operative approaches that can support the implementation of adaptive watershed management. Further work is needed to address some of the complexities and uncertainties underlying the proposed approaches, including data resolution, model calibration, and above all participation of real-life stakeholders.

Chapter 1

Scope and outline of the thesis

1.1 Introduction and objectives

Cities offer a unique perspective for promoting sustainability transitions, i.e. transitions towards patterns of development that aim to meet human needs while conserving life-supporting ecosystems (Levin and Clark 2010). Human wellbeing in cities, often associated to availability of engineered structures, is increasingly acknowledged as underpinned by goods and services provided by ecosystems (MA 2005). Ecosystems consist of living and non-living components that interact as complex dynamic systems, of which humans are an integral part (MA 2005). Ecosystem services are the direct and indirect contributions of ecosystems to human wellbeing (TEEB 2010). Yet, ecosystems services do not flow effortlessly to beneficiaries. They require appropriate management in the area of production and human input in the form of knowledge, infrastructure, labor, and governance, to be generated, transported and equitably distributed (Daw et al. 2011, Braat and Groot 2012, Burkhard et al. 2014, Haase et al. 2014, Schultz et al. 2015, Albert et al. 2015). The urban water sector is a good case in point. Delivery of water services is underpinned by key ecosystems services, including as water provision and quality regulation (e.g. McDonald and Shemie 2014), and at the same time, it requires adequate infrastructural and institutional arrangements to be in place (e.g. Lieberherr and Truffer 2015).

The urban water sector is faced by several challenges, such as freshwater “scarcity”, which are acknowledged as major global socio-ecological problems of the 21st century (Rockström et al. 2009, Srinivasan et al. 2012, IPCC 2014, Steffen et al. 2015). Growing awareness is that such challenges entail significant complexities and uncertainties, which no longer can be addressed effectively with “traditional” concepts of water resource management. There is need for a shift of management paradigm: from “predictions and control” to “adaptation and innovation” (Cortner and Moote 1994, Gleick 2000, Pahl-Wostl 2002, Pahl-Wostl et al. 2007, Pahl-wostl et al. 2008, Pahl-Wostl et al. 2011). The former refers to an approach that narrows problems, addresses them singularly, often overlooking the human dimension and relying on technical end-of-pipe solutions (Pahl-Wostl et al. 2011). The latter, on the other hand, emerges as a collective effort of stakeholders that engage themselves in a process of social learning, to meet an array of societal objectives (Clark et al. 2005, Pahl-Wostl et al. 2011). As put by Pahl-Wostl and colleagues, it promotes a shift towards participatory management and collaborative decision-making; increased integration of issues and sectors; management of problem sources not effects; decentralized and more flexible management approaches; more attention to management of human behavior through “soft” measures; explicit environmental goals; open and shared information sources (linking science and decision making); iterative learning cycles incorporated into the overall management approach (Cortner and Moote 1994, Gleick 2000, Pahl-Wostl 2002, Pahl-Wostl et al. 2007, Pahl-wostl et al. 2008, Pahl-Wostl et al. 2011).

However, implementing adaptive management is an arduous challenge. Firstly, it requires the linkage of diverse sets of stakeholders and knowledge systems across management levels and institutional boundaries (Kowalski and Jenkins 2015). Secondly, there is need for it to be institutionalized in a set of learning organizations, making routine decisions on use of land and water resources (Cowling et al. 2008). Focusing on the urban water sector, this study addresses these two main challenges, mainly by learning from the growing consideration on ecosystem in decision-making and impact assessment processes (Maes et al. 2012, Abson et al. 2014, Geneletti 2015, Mandle et al. 2015, and Geneletti et al. 2016). The main objective of this study is to develop and test operative approaches to support the implementation of adaptive watershed management for ecosystems services. In particular, to address the linkage of diverse stakeholders and knowledge systems across management levels and across institutional boundaries, assuming water utilities, which are key institutions that operate and maintain the urban water sector, are also “learning organizations” that can implement adaptive management. Watersheds consist of biophysically defined spatial entities, increasingly used as socio-economic units for designing and implementing strategies related to, among others, natural resource management, conservation, and poverty alleviation (e.g. Schultz 2001, Clark et al. 2005, Bahri 2012, Bennett et al. 2014, Kwayu et al. 2014).

This study explores and relies on three concepts, namely, ecosystems services, boundary work and learning organizations. The concept of ecosystem services provides a holistic approach for framing socio-ecological issues as well as for integrating different types of data (e.g. biophysical and socio-economic). Boundary work, i.e. any effort put in place to mediate between knowledge and action, informs active management of the tension arising at the interface between stakeholders with differing views on what represents relevant knowledge. Learning organization and the related concept of institutional capacity frame the role of water utilities in structuring the choice of action of individual or corporate and other collective actors within a society.

The study is organized in the four research objectives, and related questions outlined below.

Objective 1: Building a conceptual framework of the urban water sector from an ecosystem services' perspective.
Research question

- How to conceptualize the role of the urban water sector in linking and managing the feedbacks between socio-technical systems (cities and infrastructures) and ecological systems (watersheds)?

Objective 2: Empirically exploring practices of boundary work in adaptive watershed management for ecosystems services, promoted by a water utility.
Research questions

- What have been critical barriers for the transfer of knowledge into action in the case of Hannover water utility?
- Which boundary work activities have been put in place to overcome the barriers, and how are they related?
- To what extent has boundary work been effective in achieving the theoretical potential for interaction between stakeholders involved in use and production of knowledge?

Objective 3: Building and testing an approach for designing and assessing impact of watershed investments, to implement of adaptive watershed management.
Research questions

- Which activities in the Toker Watershed yield the greatest returns, under different investment scenarios? When? And where in the watershed?
- How do watershed such activities affect the provision of selected ecosystems services?
- What is the performance of different watershed investment scenarios with respect to baseline conditions?

Objective 4: Exploring water utilities as learning organization implementing adaptive watershed management.
Research questions

- What are the factors that determine the capacity of a water utility to play a key role in implementing adaptive watershed management?

The study starts by framing the urban water sector, including both infrastructures and institutions, from an ecosystems services perspective (Objective 1). Hence, it empirically investigates boundary work in a watershed management for ES that has been promoted by a water utility (Objective 2). Following, through a case study research, it builds and tests an operative approach, based on ecosystems services and boundary work, to support the design and assessment of watershed investments, aiming at implementing adaptive management (Objective 3). Finally, it explores the role of water utilities as learning organization implementing adaptive watershed management (objective 4). Methodologically, given the object of this study is complex, embedded in a real-life context and characterized by many uncontrollable variables, for objectives 2, 3 and 4 a case study approach is adopted (Yin, 2008). Moreover, objectives 2, 3 and 4 are highly interlinked: Objective 3 adapts the insights on boundary work in watershed management for ecosystems services that are gained by Objective 2. Similarly, Objective 4 investigates two water utilities previously considered as part of Objective 2 and 3, respectively. Finally, objectives 2, 3 and 4 are all embedded in the conceptual framework of the urban water sector developed as part of Objective 1.

1.2 Outline of the thesis

The outline of the thesis is shown in Figure 1.1. **Chapter 2** describes a conceptual framework of the urban water sector, including infrastructures and institutions, from and ecosystems services perspective (Objective 1). The proposed framework provides an overview of the challenges and trends of the sector. It synthesizes the most relevant aspects characterizing the exchange of water between watersheds and cities, and within the city. It highlights the key role of urban water infrastructures in (i) linking ecosystems services production and benefit areas, (ii) bridging spatial scales ranging from the watershed to the household level, and (iii) adopting ecosystems services-based responses to water vulnerability. Thus, the framework sets a background for further analysis the following chapters, focusing on adaptive watershed management for ecosystems services, with water utilities as central actors.

Chapter 3 addresses barriers and bridges for knowledge into action transfer, drawing on the literature on bridging organizations and boundary work (Objective 2). It empirically investigates how boundary work can facilitate knowledge co-generation, transfer, and cooperative application in a case study of adaptive management for ecosystems services in Fuhrberg watershed, Germany. The empirical results suggest that scientific insights have been crucial for “enlightenment”, “decision-support”, and in the “negotiations” between the water utility and the stakeholders in Fuhrberg watershed management. The chapter provides one of the first empirical assessments of boundary work in practice and presents many promising approaches for initiating boundary work in the case of water utilities.

Chapter 4 focuses on watershed investments to secure water for cities, seen as a promising way of implementing adaptive watershed management in real-life (Objective 3). Through a case study research, the chapter proposes an operative approach for designing and assessing impact of multi-purpose watershed investments. The approach is based on spatially explicit modeling of ecosystems services and on boundary work for watershed management. The approach was applied to a case study involving a watershed that supplies a medium-sized city, in a data-scarce context in Sub-Sharan Africa. The Toker Watershed, which supplies water to the Eritrean capital Asmara, was considered as a case study, addressing by way of example challenges related to soil erosion and water scarcity. Urban water security and rural poverty alleviation were adopted as two illustrative objectives for watershed investment. The case study application produced spatially explicit data (investment portfolio, land use scenario, impact on ecosystems services) that allowed to quantitatively assessing the performance of watershed investments in terms of changes in a selected ecosystems service. Thus answering the three research questions related to Objective 3, which also represent important planning and management questions. The results show how, by addressing stakeholders' concerns of credibility, saliency and legitimacy, the proposed approach can facilitate negotiation of objectives, definition of scenarios, and assessment of alternative watershed investments. Ultimately, it can contribute to implementing adaptive watershed management.

Chapter 5 assumes that water utilities are learning organizations and explores their role as learning organization implementing adaptive management for ecosystems services. A learning organization is an organization that is skilled at creating and acquiring knowledge and modifying its behavior to reflect new insights (Cowling et al., 2008). To this end, an analytical tool was applied to evaluate the institutional capacity of two water utilities involved in the two case studies, previously considered in Chapter 3 and 4. Hence, used to discuss the determinants of capacity that are the most significant for understanding the role of water utilities in implementing adaptive watershed management.

Finally, **Chapter 6** summarizes the results of the research, discusses the main findings, their strengths and weaknesses, and contains some recommendations for future research.

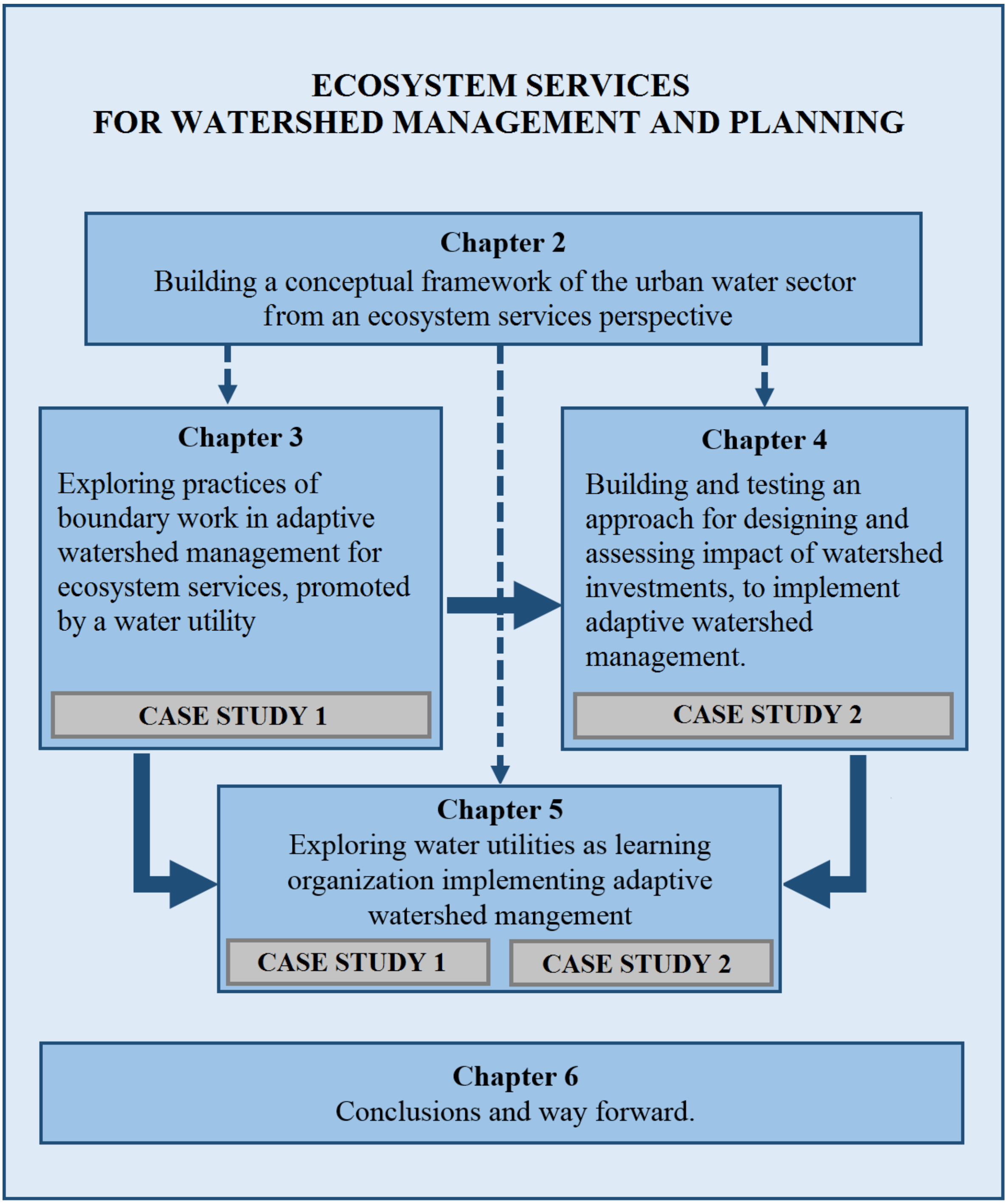


Figure 1.1: Outline of the thesis

Chapter 2

The urban water sector and ecosystem services: a conceptual framework

2.1 Introduction and aim

In this chapter, my aim is to provide a conceptual framework of the urban water sector from an ecosystems services perspective as a background for further analysis. Here, by urban water sector, I refer to urban water infrastructures and institutions that operate and manage them, water utilities in the first place. Urban water infrastructures include water supply, sanitation and drainage systems. They consist of engineered and non-engineered structures, equipment and facilities that are needed to deliver water services for both economic production use and household use (World Bank 1994). Therefore, I relied on internationally accepted approaches and concepts used in the urban water sector. By way of example, I mention here the System of Economic and Environmental Accounting for Water – SEEA-Water (UN-DESA 2011) and Integrated Urban Water Management - IUWM (Medema et al. 2003, Bahri 2012), which inspired the structure of the proposed framework, as will be discussed later on. In the remainder of this chapter, I described the framework and I presented the literature that underpins its concepts and structure. Finally, I provided an example of its application as a tool for reviewing real-life projects of urban water infrastructures.

2.2 Description of the framework

Figure 2.1 shows the conceptual framework of the urban water sector from an ecosystems services perspective. It is in essence a synthesis of the most relevant aspects characterizing the exchange of water between watersheds and cities, and within the city, based on an original review of the literature. It highlights the role of urban water sector in (i) linking ecosystems services production and benefit areas, (ii) bridging spatial scales ranging from the watershed to the household level, and (iii) adopting ecosystems services-based responses to water vulnerability. It is structured in four columns, entitled: Urban water infrastructures, Spatial scale, Ecosystem service, and ES-based response.

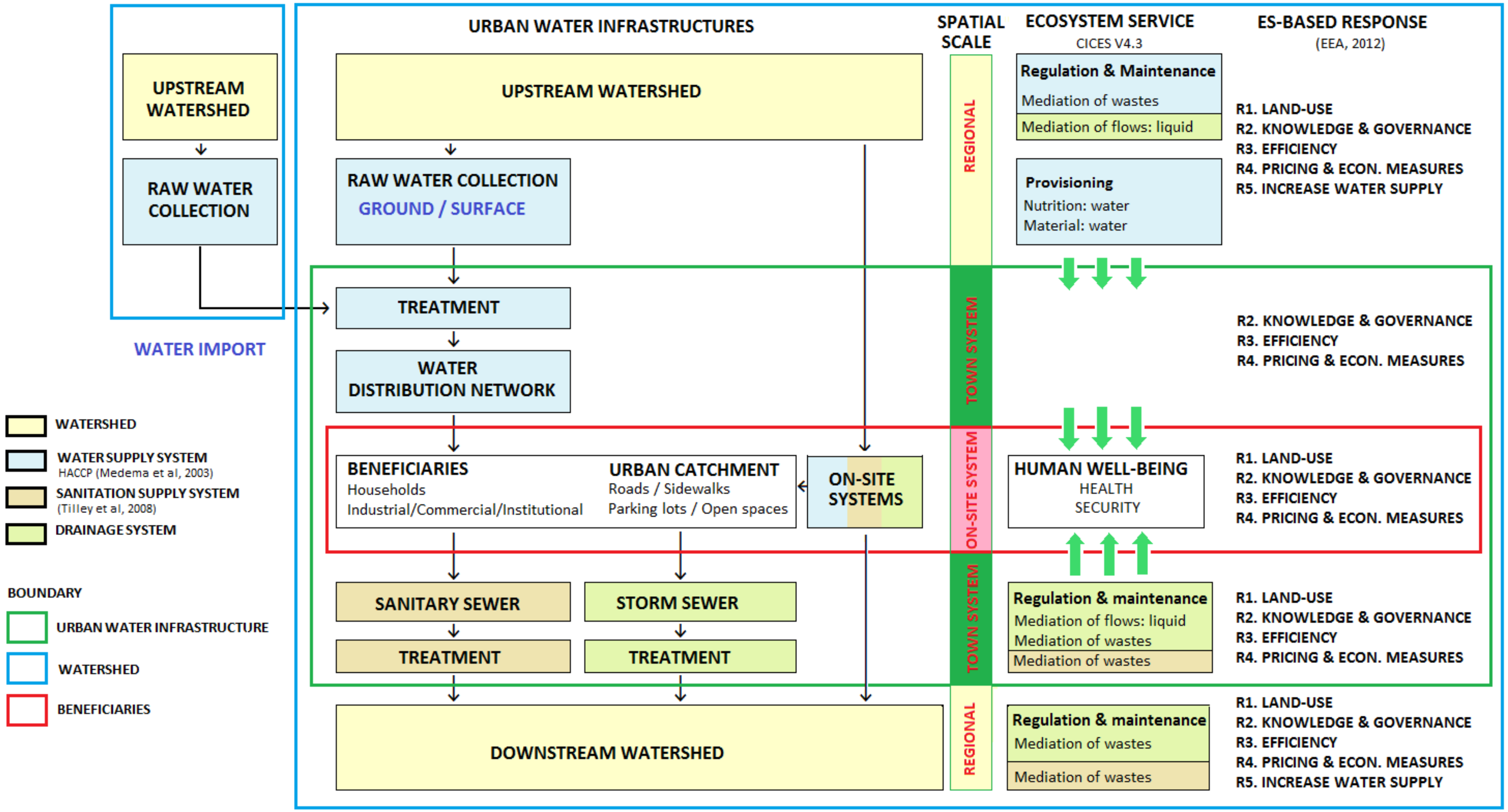


Figure 2.1: Conceptual framework of the urban water sector from an ecosystem services perspective. Thin black arrows represent the flow of freshwater and wastewater; thick green arrows represent the flow of ecosystem services. Colors distinguish different components; e.g., the water supply system and related ecosystem services are blue. Three boundaries define the watershed (blue), urban water infrastructures (green), and beneficiaries (red). Town Systems and on-site system represent underlying two trends: "Progressive improvement" and "Decentralization".

2.2.1 Urban water infrastructures

Water infrastructures play a role in the exchange of water between upstream watersheds and urban beneficiaries (water supply system) and between urban beneficiaries and downstream watersheds (sanitation, and drainage systems). In this context, to characterize the urban water sector, I adopted a simple and frequently used distinction between “Town systems” and “On-site Systems” or facilities (Choguill 1996, 1999). The former consist of centralized infrastructures, generally built and managed by municipalities to serve the central areas of cities and areas where high-income residences are located. The latter include all the means by which the poor in underserved areas meet their basic needs related to water supply, sanitations and hygiene; they include pit latrines, septic tanks and drinking-water wells. This dichotomy is characteristic of many cities in the developing world, where a formal and informal sector coexist, as well illustrated, for instance, in a joint WHO and UN-Habitat publication entitled “Hidden cities” (WHO and UN-HABITAT 2010).

Quite interestingly, two trends characterize the urban water sector. On the one hand, there is the idea of a “progressive improvement”, according to which on-site systems can be planned and implemented so that with time they can meet desirable standards, and eventually become integral part of town systems (Choguill 1996, 1999). In fact, with the right mix of policies in place (e.g. land tenure and infrastructure ownership) and proper technical support, communities could self-build their own infrastructures. A good working example is the case of the Orangi District of Karachi, Pakistan, where an unauthorized, low-income community, with a population of about 800,000, has successfully developed and built its own sewer system (Choguill 1999, Bahri 2012). Indeed, for most cities in the developing world, this could be a good or perhaps the only viable solution.

On the other hand, sustainability of traditional town systems (i.e. providing potable water and flushing toilets in every household) is increasingly questioned in several respects: environmental (e.g. resource protection), social (e.g. security of supply), and financial (e.g. cost recovery and affordability) (Lieberherr and Truffer 2015). In fact, there is also an opposite trend to the above-mentioned “progressive improvement”, which tends to favor more decentralized solutions. For instance, according to Richter et al (2013) a typical water development pattern in cities starts with (i) exhaustion of local water resources followed by (ii) water import from adjacent watersheds, hence (iii) introduction of water conservation measures, and finally (iv) adoption of more local solutions, such as storm and rainwater harvesting or seawater desalination. These findings are particularly relevant given that 50% of cities with more than 100.000 inhabitants insist in watersheds that are characterized by water scarcity (Richter et al. 2013).

2.2.2 Spatial scale

Spatial scales range from region (e.g. watershed) to city (e.g. town systems) and finally to household level (e.g. on-site system). In the framework, less evident are however the implications relating to temporal scales, ranging from annual and seasonal variations (e.g., rainfall patterns at the watershed level) to instantaneous, individual demands for tap water by users (e.g., coping with so-called “toilet-peak” during football matches). Put simply, the former determine availability of water resources and are crucial for planning purposes, while the latter are related to the end-users’ demand and perception, and are important for management goals.

Figure 2.2 provides a schematic representation of how urban water infrastructures link the areas of ecosystem services production (watershed boundary) and of benefit (city boundary), distinguishing between upstream and downstream watersheds. An interesting aspect deals, in fact, with the direction of the flow of ecosystem services, which may coincide with the flow of the water (water supply systems) or could be in the opposite direction (sanitation and drainage systems). Figure 2.2 also highlights possible differences between neighborhoods in the access to benefits from ecosystem services, due to diverse infrastructural coverages (e.g. town system and on-site system) and generally to the underlying socio-economic conditions, including issues of poverty. For the latter, Banerjee and Duflo (2011) argue that the most significant socio-economic variables to be considered are those dealing with health, food, education and family. In particular, they suggest adopting “randomized controlled trials” as a strategy for gaining deeper understanding of a specific socio-economic context and possible interventions. Thus, they claim that “it is possible to make significant progress against the biggest problems in the world through the accumulation of a set of small steps each well thought out, carefully tested, and judiciously implemented” (Banerjee and Duflo 2011).

Indeed, the aspect mentioned above that deal with spatial scale and distribution can have significant and complex implications in terms of management, planning, and policymaking. Thus, in the proposed framework of the urban water sector, they were considered, for instance, by adding different boundaries (watershed, urban water infrastructure, beneficiaries), distinguishing between upstream and downstream areas, including both town system and on-site systems, and specifying the direction of the flow of ecosystem services, among others.

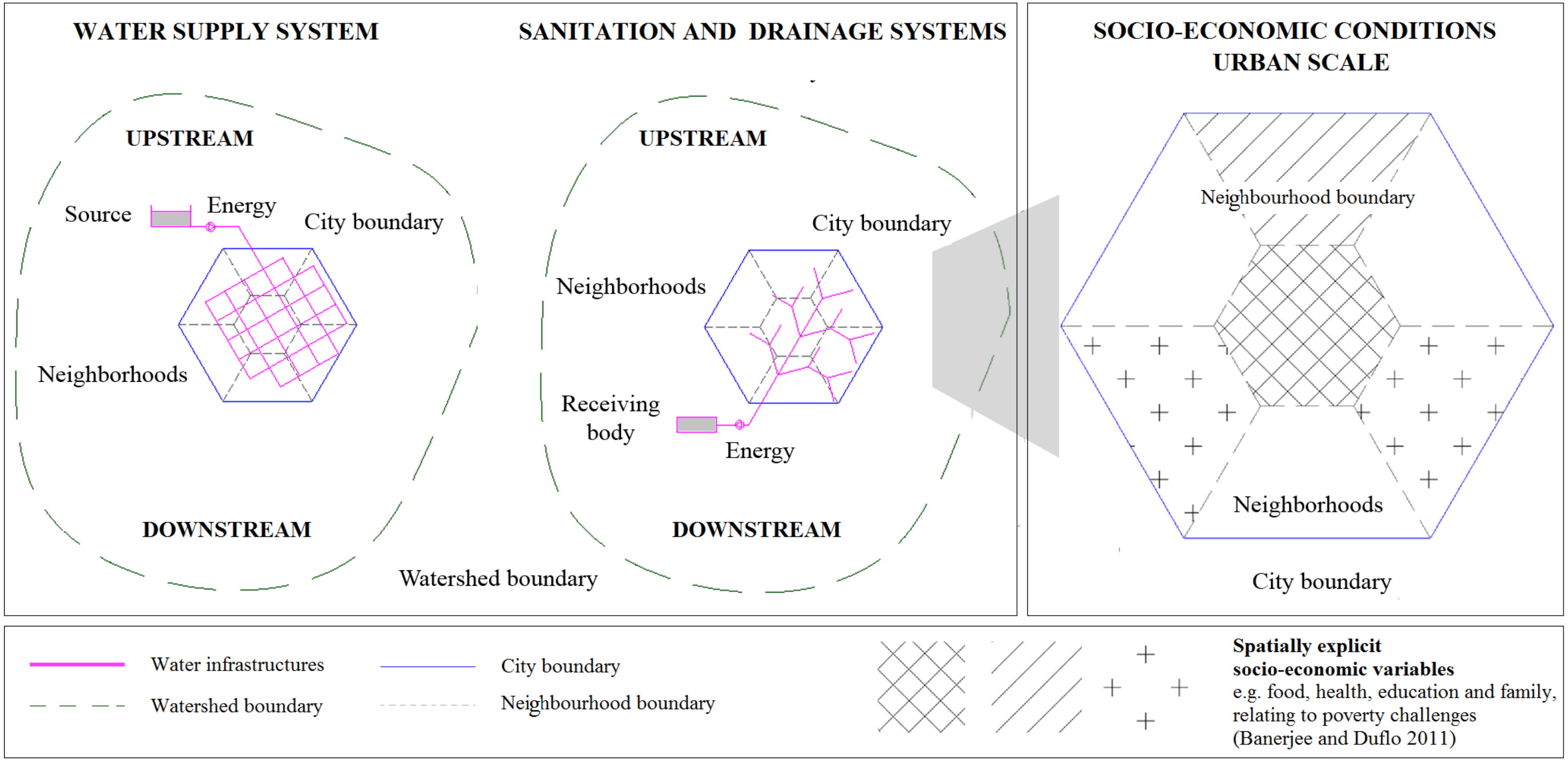


Figure 2.2: Left: Schematic spatial representation of the role of urban water infrastructures in the flow of ecosystem services from areas of production (watershed boundary) to areas of benefit (city boundary). Distinction between upstream and downstream watersheds. Highlight on lack of infrastructural coverage in some neighborhoods, resulting in different levels of access to benefits from ecosystems. Right: Zoom on the urban scale to show different socio-economic condition that characterize neighborhoods within the city. Symbols represent spatial distribution of relevant socio-economic variables. For example, according to Banerjee and Duflo, for poverty challenges four key variables to investigate are food, health, education and family.

2.2.3 Ecosystem services

The third column in Figure 2.1 identifies the main ecosystem services that are intercepted by the different components of an urban water infrastructure as well as their contribution to the well-being of the people in cities. These are provisioning and regulating ecosystem services, contributing mainly in terms of security, health and livelihood of urban dwellers and activities. In this context, among the many classifications of ecosystem services (Boyd and Banzhaf 2007, Fisher et al. 2009, Crossman et al. 2013, Gómez-Baggethun and Barton 2013), I adopted the Common International Classification of Ecosystem Services (CICES V4.3) (EEA 2013), developed under the auspices of the European Environmental Agency (EEA). Table 2.1 shows the main ecosystem services intercepted by the urban water sector.

Table 2.1: The main ecosystem services intercepted by the urban water sector, classified according to the CICES V4.3 (source: EEA 2013)

Section*	Division**	Group***	UWI
1. Provisioning	1.1 Nutrition	1.1.1 Water (surface/ground)	WSS
	1.2 Materials	1.2.1 Water (surface/ground water)	WSS
2. Regulation & Maintenance	2.1 Mediation of waste, toxics & other nuisances	2.1.1 Mediation by biota remediation/filtration/sequestration	WSS - SS
		2.1.2 Mediation by ecosystems	WSS - SS
	2.2 Mediation of flows	2.2.1 Liquid flows (hydrological cycle/flooding)	WSS-SS-DS

* Categories of ES, according to the CICES V4.3
** section categories by types of output or process
*** division categories by biological, physical or cultural type or process
UWI: Urban water infrastructure WSS: Water supply system SS: Sanitation system DS: Drainage system

The spatial mismatch between areas of ecosystem service production and benefit has implications in terms of sharing the benefits and costs for the maintenance of ecosystems and their services. Moreover, access to benefits from ecosystem services by city inhabitants is diverse, mainly due to different levels of coverage by urban water infrastructures. Quite interestingly, two aspects can be framed from an equity perspective. Equity is indeed a complex and ambiguous concept. Nevertheless, following Abebe et al. (2008), it was here simplistically characterized by two fault lines: a geographical (spatial) fault line, related to the distribution of people in the territory (e.g. watershed versus city), and a social fault line, related to how sub-groups within a community are formed (Abebe et al. 2008). Therefore, while referring to Lamorgese and Geneletti (2015) for a comprehensive theoretical framework concerning (inter and intra-generational) equity, I here adopted a more pragmatic approach. In fact, in pursuing equity as a societal goal it is agreed on that decision-making should rely on sufficiently disaggregated analysis (Daw et al. 2011, Ernstson 2013). Disaggregation is to be carried out with reference to both ecosystem services, to understand existing trade-offs, and the beneficiaries to identify losers and winners. The extent to which analysis should be disaggregated is dependent on the level of existing inequities: the higher the inequities the more disaggregated the analysis should be (Daw et al., 2011). Equity, on its turn is related to the fight against poverty, hence is closely linked to the availability and changes in ecosystem services (MA, 2005). Therefore, in the proposed framework of the urban water sector, I found it necessary to include both town system and on-site facilities, thus implicitly recalling the underlying opposing trends and, ultimately, the issues of inter and intra-generational equity.

2.2.4 Ecosystem services-based response

The last column in Figure 2.1 specifies, by way of example, a set of ecosystem services-based responses aiming at mitigating the drivers of water vulnerability, i.e. risks of flooding, drought, and water scarcity. As shown in Table 2.2, the ecosystem services-based responses are those suggested by the European Environmental Agency (EEA). In the proposed framework, water vulnerability and the related concept of natural water variability were selected to be representative of the diverse set of challenges facing the urban water sector. Similarly, ecosystem services-based responses are illustrative of one of the most cost-effective way to face water vulnerability. In fact, natural water variability and water vulnerability are two concepts increasingly proposed as guiding principles for water planning and management within the European context (EEA 2012, Vanneuville et al. 2012, Werner and Collins 2012). The former refers to the variation of the water content that occurs according to the seasons, geography of the region, and the types of water bodies; it takes place in the form of droughts and flooding (Vanneuville et al. 2012). Water vulnerability is defined as the exposure of water ecosystems and society to human-caused shortages and excesses of water, and takes place in the form of risks of flooding, droughts and water scarcity (Vanneuville et al. 2012). Accordingly, ecosystem services-based responses to drivers of water vulnerability are considered the best way to improve water quality and minimize water scarcity and floods (Werner and Collins 2012). They aim at "ensuring that healthy ecosystems are able to function as habitats for a rich biodiversity and, at the same time, are able to retain water in a natural way and help regulate the hydrological cycle, purifying and filtering water to provide humans and nature with enough clean water" (Vanneuville et al. 2012).

Table 2.2: Ecosystem services-based response to drivers of water vulnerability (source: Burek et al. 2012, Schmidt and Benítez-Sanz 2012, Vanneuville et al. 2012)

FLOODS RISKS	R1.	Restrictions to land-use: favor natural water retention measures (NWRMs), by restoring wetlands, increasing forest cover, enhancing natural features of floodplains, reducing impervious surfaces in cities
	R2.	Knowledge and governance: assessing the natural water variability (concept of "flow regime"); adopt a risk management rather than a crisis management approach. The former accepts the occurrence of flooding and drought, but tries to mitigate their effects with preventive action, at a relatively lower societal cost.
DROUGHT & WATER SCARCITY	R1.	Restrictions to land-use: favor natural water retention measures (NWRMs)
	R2.	Knowledge and governance: knowing at any given time and location exactly what water is available for human use and for ecosystems.
	R3.	Efficiency: increase water efficiency at the household, industry and irrigation
	R4.	Pricing and Economic measures: water pricing and metering to change consumption style, taxes and subsidies to discourage water use in certain places and times, thus allocate water resources between competing sectors
	R5.	Increase water supply: synergies with the other sectors to reduce pressure (e.g. increase efficiency of irrigation systems, fight against invasive alien plants

Among the ES-based responses shown in Table 2.2, a sub-set includes so-called "natural water retention measures". They consist of measures that aim to reestablish the natural water variation by acting on land-use and resulting land cover, which constitute the main factor affecting the provision of ESs. Table 2.3 provides some examples of natural water retention measures based on an EEA-funded research by Stella Consulting (2012), which investigated the impacts of different natural water retention measures.

Table 2.3: Examples of Natural Water Retention Measures in different contexts (source: Vanneuville et al. 2012)

Urban	Agricultural
Filter strips and swales	Restoring, maintaining meadows & pastures
Permeable surfaces and filter drains	Buffer strips
Infiltration devices	Soil conservation crop practices
Green roofs	No or reduced tillage
	Green cover
	Early sowing
	Traditional terracing
Forest	**Water storage**
Continuous Cover Forestry	Basins and ponds
Maintaining and developing riparian forests	Wetland restoration and creation
Afforestation of agricultural land	Floodplain restoration
	Re-meandering
	Restoration of lakes
	Natural bank stabilization
	Artificial groundwater recharge

More in general, the challenges of the urban water sector have been addressed from at least three different perspectives that can be summarized as role of social actors, role of water utilities, and a global perspective (Srinivasan et al. 2012, Domènech et al. 2013, Lieberherr and Truffer 2015). In Appendix 1, I proposed a review of three illustrative papers.

2.3 Relationship with other frameworks

2.3.1 MA and TEEB ecosystem services frameworks

In order to integrate the urban water sector within an ecosystem services perspective, I considered the two most consolidated frameworks: the Millennium Ecosystem Assessment, MA (MA, 2005) and the Cascade Model of The Economics of Ecosystems and Biodiversity, TEEB (Haines-Young and Potschin 2010, de Groot et al. 2010, Braat and Groot 2012). Through the MA, I identified the main ecosystem services and the constituents of human wellbeing involving the urban water sector. Through the TEEB, I highlighted the role of key institutions in the sector in determining the use of ecosystem services by managing ecosystems as well as feedbacks with human systems. Hence, I coupled these ecosystem services-frameworks with typical conceptual representations of urban water infrastructures, identifying their components that interface with ecosystem services, such as the “source” in a water supply system (see Figure 2.3).

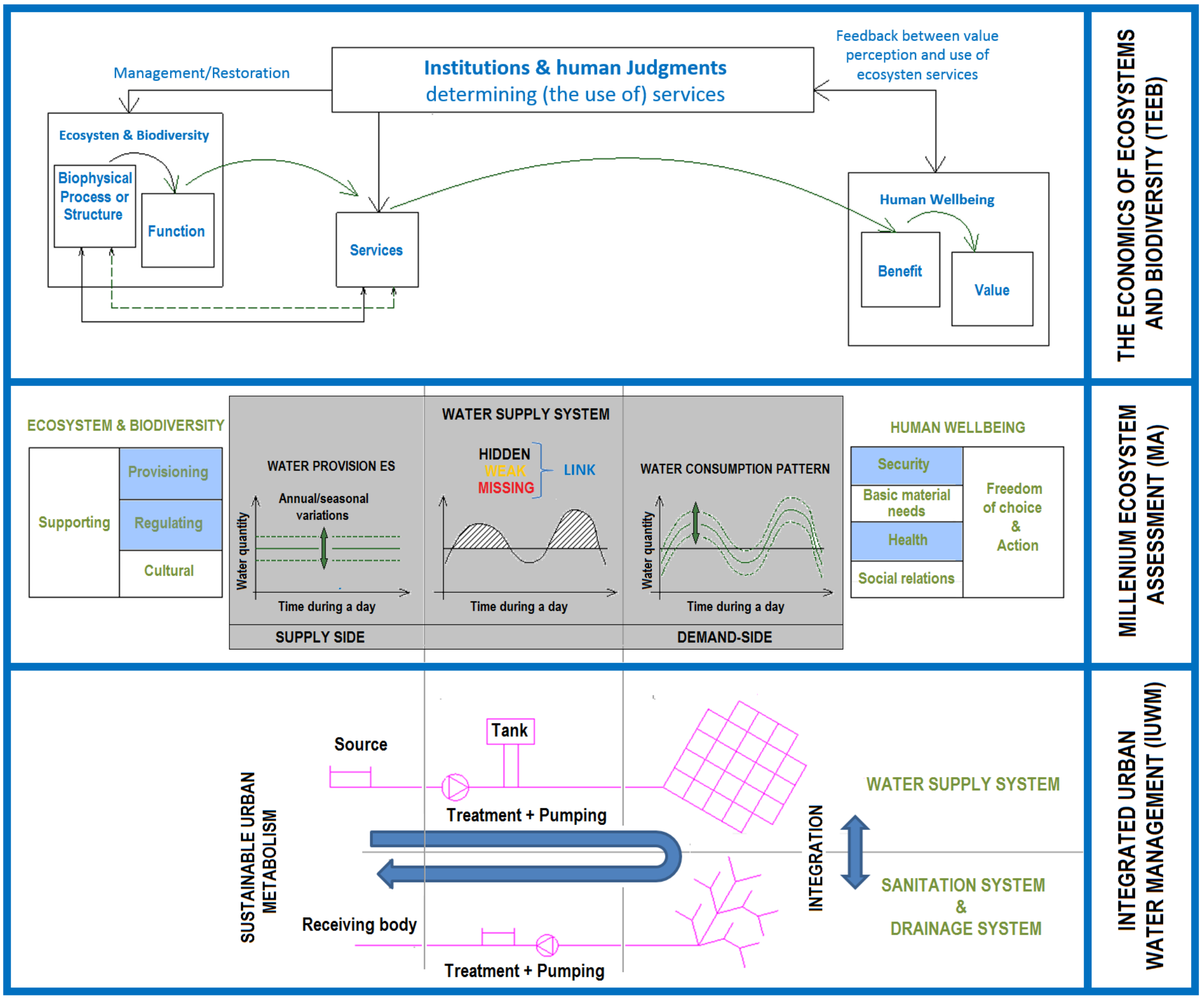


Figure 2.3: Integrating the urban water sector within MA and TEEB ecosystem services frameworks and IUWM's concept of "sustainable urban metabolism". Example of the water supply system (grey Box).

In Figure 2.3, I showed how the urban water sector (both infrastructures and institutions) plays a crucial role in the flow of key ecosystem services to people in cities. Urban water infrastructures, by physically linking areas of ecosystem services production and benefit (i.e. watersheds and cities, respectively), allow the flow of important provisioning and regulating ecosystem services, thus underpinning human wellbeing mainly in terms of health, security, and livelihood. Water utilities play a key role in managing the links and feedbacks between cities, infrastructures, and watersheds, i.e. between socio-technical and ecological systems. As central actors in the urban water sector, they are in a position to affect the feedback between value, benefit and use of water-related ecosystem services (socio-technical side) as well as to deal with the management and restoration of ecosystems (ecological side).

More in detail, I reported as an example the case of a water supply system (see grey box in Figure 2.3). On a daily basis, water provision at the source could be considered more or less constant, whereas water consumption shows patterns that reflect the prevailing socio-economic and cultural habits of the users (e.g. morning and evening peaks). Yet, both water provision and consumption may have significant annual or seasonal fluctuations. Therefore, the urban water sector plays an important role in linking and balancing the demand and supply sides, at daily, seasonal, and annual temporal scales. However, this important contribution is often unacknowledged, especially by end-users, because water infrastructures are "hidden" underground (case of rich countries). More than often the contribution does not take place because infrastructure are completely missing (case of poor countries). In all cases, it tends to be weak mainly due to aging and leaking infrastructures, and weak institutions.

2.3.2 SEEA-Water framework

The proposed framework was purposely structured in accordance with the conceptual foundation of the SEEA-Water (UN-DESA 2011). Developed by the United Nations Statistics Division (UNSD), the SEEA-Water consists of standardized concepts and methods in water accounting. It allows organizing economic and hydrological information, enabling a consistent analysis of the contribution of water to the economy and of the impact of the economy on water resources (UN-DESA 2011). In accordance with the SEEA-Water, I structured the proposed framework distinguishing between upstream and downstream watersheds, which is useful for properly framing the diverse challenges they face. In particular, I used (thin black) arrows to indicate the flow of freshwater/wastewater through either town-system or on-site systems. For the sake of ease of application and flexibility, I preferred to use layperson terms (e.g. households, commercial users, roads and sidewalks) instead of the standardized sector codes used in the SEEA-Water, based on the “International Standard Classification of all Economic Activities” (ISIC Rev.4). Therefore, the proposed framework is both intuitive (e.g. represents the urban water cycle using layperson terms and arrows) and flexible (e.g. can be easily adapted to meet the context-specific needs and the desired levels of detail and complexity). At the same time, it relies on the conceptual foundation of the SEEA-Water, which allows easily drawing from the rich set of indicators and methods it provides.

2.3.3 Integrated urban water management

Integrated Urban Water Management (IUWM) is an approach that is increasingly proposed as way forward to address diverse challenges facing urban water sector (Medema et al. 2003, Bahri 2012). Among others, underlying the IUWM is the concept of “sustainable urban metabolism” as opposed to an “unbalanced urban metabolism” (e.g. cities simply importing freshwater from the watershed and releasing wastewater) (Novotny 2010, Bahri 2012). Put simply, IUWM advances an integrated management of the whole water cycle within the city. In Figure 2.3, noteworthy are the two blue arrows representing the concept of sustainable urban metabolism, which in turn requires good understanding of the different systems. To this end, and by way of example, I have here reported some considerations regarding sanitation systems, based on a review of a compendium (Tilley et al. 2008, 2014).

As shown in Figure 2.4, the compendium identified eight “Sanitation System Templates”, each composed of a number of “Functional Groups” (e.g. user-interface, collection/storage and conveyance) that employ different technologies. For each technology, the compendium provided information about its suitability, specifying optimal scale of application and level of management. In Figure 2.4, I proposed a possible reorganization of such information, aiming to address questions about suitability of sanitation systems. For each Sanitation System Template, by aggregating the information about single technologies, I identified the optimal scale of application and level of management. Figure 2.4, which shows the results of my analysis of the information about sanitation systems, can be a useful entry point to the rich content of the Compendium. Moreover, it is a good example that shows the entire spectrum of solutions: from an advanced Town system to a basic One-site system. Finally, it illustrates how similar analysis could be carried out for other urban water infrastructures, thus exploring mutual interactions.

** Most suitable | * Less suitable | Not suitable

	HH / HH	NH / SH	C / PU
S. 1 SINGLE PIT SYSTEM	**		
S. 2 WATERLESS SYSTEM WITH ALTERNATING PITS	**		
S. 3 POUR FLUSH SYSTEMS WITH TWIN PITS	*	**	
S. 4 WATERLESS SYSTEM WITH URINE DIVERSION	**		
S. 5 BLACKWATER TREATMENT SYSTEM WITH INFILTRATION		*	
S. 6 BLACKWATER TREATMENT SYSTEM WITH SEWERAGE		**	*
S. 7 (SEMI-) CENTRALIZED TREATMENT SYSTEM		**	**
S. 8 SEWERAGE SYSTEM WITH URINE DIVERSION		**	**

HH - Household NH / SH - Neighbourhood / Shared C / PU - City / Public

Figure 2.4: The level of suitability of eight “Sanitation System Templates” identified in the compendium by Tilley et al (2008); suitability refers to the optimal scale of application and level of management.

2.4 Illustrative application of the framework

In this part, I described the illustrative application of the proposed conceptual framework as a tool for reviewing real-life projects dealing with urban water infrastructures. I considered five major projects funded by the World Bank over the past ten years, and located in Eastern Africa. I selected this area assuming it to be characterized by several socio-ecological challenges as well as a high demand for new infrastructures. Figure 2.5 shows the selection criteria, which included definition of the “sector” and “theme”, period of time, and geographic region. Sector is a high level grouping of economic activities based on types of goods or services produced; theme refers to the pursued goal and priority.

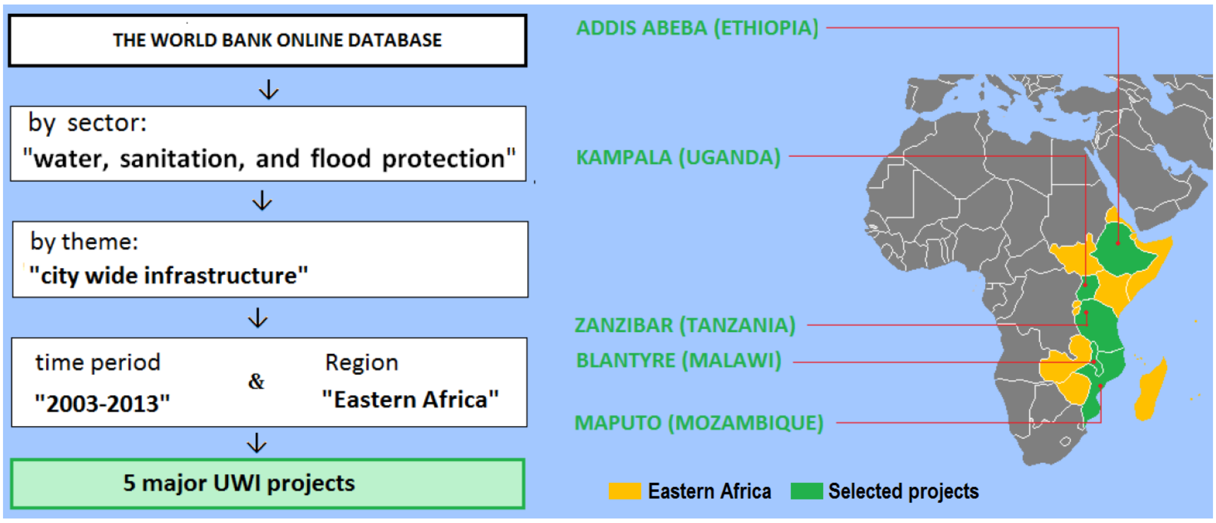


Figure 2.5: Search and selection of real-life water infrastructure projects for review

For each project, I reviewed three types of documents: i) project paper, ii) EIA document, iii) resettlement plan. Table 2.4 shows the information I reviewed. Operatively, I used the proposed framework of the urban water sector as a tool for a systematic reorganization of information scattered over the different project documents. Hence, I used a binary scoring system to assess the coverage of each part of the conceptual framework.

Table 2.4: Types of reviewed project documents from the World Bank Database

Reviewed document	**What to look for?**
A. Project paper & information	
Country and Sector background	• Significant water related challenges (flooding & water scarcity), • Other drivers of water vulnerability in cities (population growth, poverty, natural resources conservation, climate change).
Project development objectives	• Strategies to face water challenges in order to meet general development needs. • Strategies to achieve long-term human wellbeing without depleting the sustaining ecosystem services.
Project description	• Actions that are actually included in the projects, and extent to which they represent an ES-based approach.
B. EIA document	
	• Degree of awareness of the impact to society and ecosystems. • Insight on trade-offs and synergies that are identified as most significant, and the way they are dealt with
C. Resettlement plans	
	• Insight on how the mismatch between ecosystem service production and benefit area is addressed.

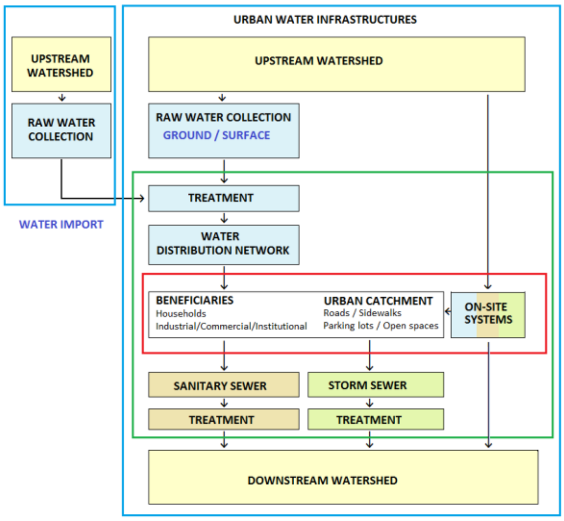
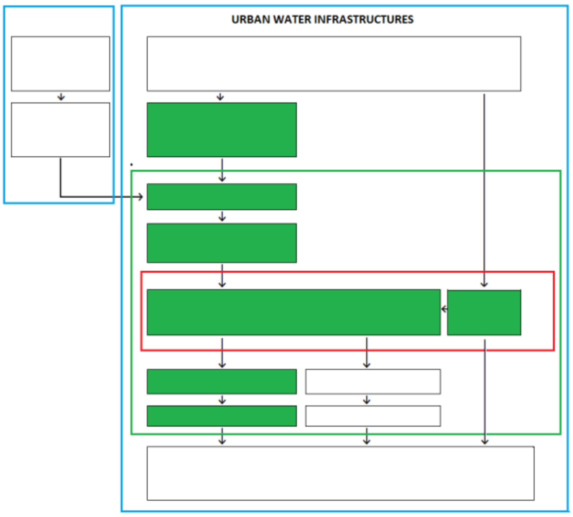
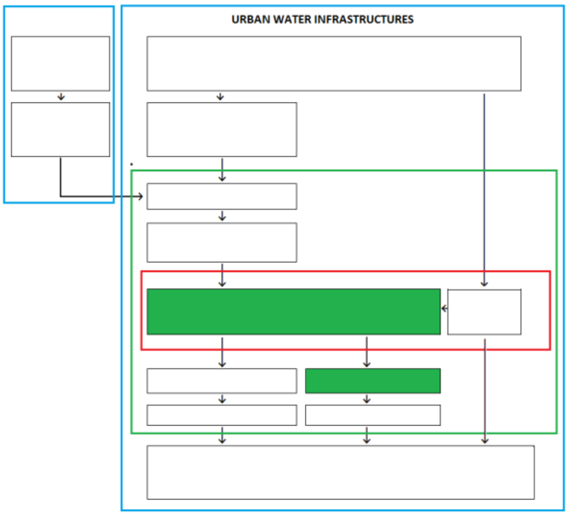
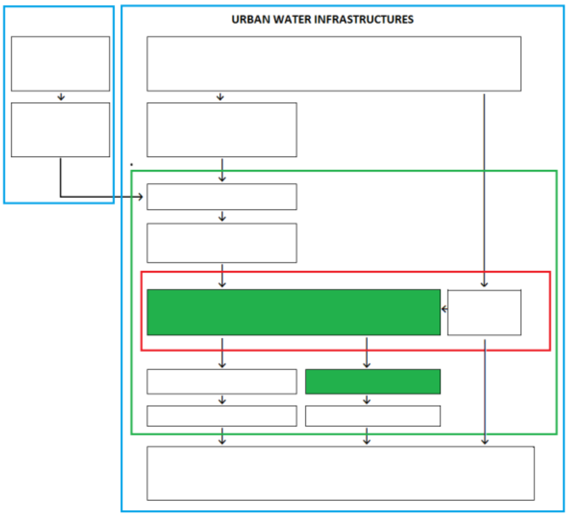
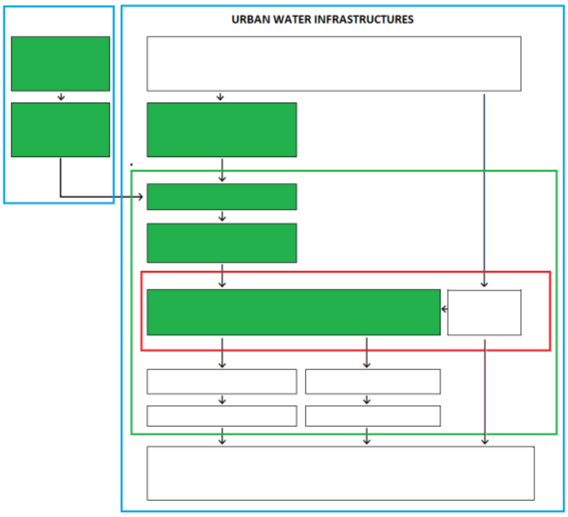
Table 2.5 shows the five reviewed projects, specifying the budget and development objectives. They all had both an “infrastructural” and an “institutional and capacity building” component; I only focused on the first part. They all addressed a single urban water infrastructure, except for the case of Addis Ababa and Blantyre, which in addition to their water supply system they considered the sanitation and drainage system, respectively. The five projects mainly dealt with town systems; yet, on-site systems were mentioned in the case of Addis Ababa (e.g. “*in high income residential areas sanitation will be based on on-site septic tank systems financed by the owner*”) and Blantyre (e.g. “*construction of 100 kiosks*”). The five projects provided detailed information about the project beneficiaries (indirectly, ES beneficiaries), specifying their present and future demands. The Maputo project is the only one that mentioned import of water from other watersheds. The concept of ecosystem services was not expressly used as a holistic framework; yet, water-provisioning ecosystem services was more clearly identified than the regulating services. Only the Kampala project explicitly mentioned the use of ecosystem services-based enhancement of tertiary treatment of effluent, by restoring wetlands. While the Malawi project included the establishment of a pilot Catchment Management Authority to promote, among other, the “preservation and enhancement of key environmental systems”.

Table 2.5: Five water infrastructure projects from the World Bank Online Database, reviewed using the proposed framework (Project location, budget, title, and development objective).

Addisa Ababa (Ethiopia) $100 +$85 million	Urban water supply & sanitation Project Development Objective: (a) to produce and distribute more water and improve sanitation services in Addis Ababa and other targeted secondary cities, (b) to improve operational efficiency (...), and (c) to improve governance by the water boards and to introduce performance incentives for operators.
Kampala (Uganda) $33.6 million	Kampala institutional and infrastructure development adaptable program Project Development Objective: Develop a strong governance and institutional structure () to enhance service delivery and improve the economic performance of Kampala, through: (a) a program of institutional and fiscal reform (..) and (b) a program of investment at the city-wide scale, focusing on the areas of drainage, roads/traffic management, and solid waste removal.
Blantyre (Malawi) $120 million	Second national water development project. Project Development Objective: (A) increase access to sustainable water supply and sanitation services for persons living in cities, towns, villages, and Market Centers within the Recipient’s territory; and (B) improve water resources management at the national level.
Zanzibar (Tanzania) 38 million	Zanzibar urban services project Project Development Objective: Improve access to urban services in Zanzibar and conserve the physical cultural heritage at one public location within the Stone Town"
Maputo (Mozambique) $178 million	Greater Maputo water supply expansion. Project Development Objective: Increase access to clean water for residents in the Greater Maputo Area.

Unfortunately, the information included in the reviewed documents did not allow for an in-depth analysis of the local urban water sector from an ecosystem services perspective, as originally intended. The information was too specific of the project, thus additional material would have been needed in order to be able to reach meaningful conclusion about the urban water sector in general. However, the review provided insights about the key aspects synthesized in the proposed framework that have been considered in the urban water infrastructure projects. Based on the information in the reviewed documents, as shown in Table 2.6, I have colored in green the components of the conceptual framework that are actually mentioned. This was the most that could be done reasonably, without referring to additional material, which would have been beyond my scope in this chapter.

Table 2.6: Result of the review of five real-life water infrastructure projects (if a component of the proposed framework is green, it means that it is addressed in the project documents, yet, without specifying the level of detail).

Proposed framework	**Addis Ababa (ETHIOPIA)**
	
Kampala (UGANDA)	**Blantyre (MALAWI)**
	
Zanzibar (TANZANIA)	**Maputo (MOZAMBIQUE)**
	

2.5 Concluding remarks

Indeed, the aim of this chapter was broad and challenging, involving multiple systems and concepts: for example, water supply and sanitation systems, water governance, engineering design, water accounting and ecosystem services. In other words, it attempted to represent what Pahl-Wostl (2011) define a management paradigm. A paradigm consists of “a set of basic assumptions about the nature of the system to be managed, the goals of managing the system and the ways in which these goals can be achieved, shared by an epistemic community of actors involved in the generation and use of relevant knowledge”. The paradigm is manifested in artefacts such as technical infrastructure, planning approaches, regulations, engineering practices and so on (Pahl-Wostl et al. 2011). Therefore, the findings of this research and the proposed framework are arguable, not exhaustive and hardly reach the level of detail that would be needed to gain an actual understanding of the urban water sector. Nevertheless, despite these limitations, they can be a useful starting point for seeking a better understanding of the complex relationship between long-term human wellbeing in cities and the respective service providing and life-supporting watersheds.

The proposed framework synthesized the most relevant aspects characterizing the exchange of water between watersheds and cities, and within the city. It highlighted the role of urban water infrastructures in (i) linking ecosystem services production and benefit areas, (ii) bridging spatial scales ranging from the watershed to the household level, and (iii) adopting ecosystem services-based responses to water vulnerability. A possible application of the framework is as a tool for reviewing infrastructural projects. By reorganizing the information, it could be used to assess the extent to which the different aspects characterizing the framework (e.g. ecosystem services-based response, IUWM) have actually been taken into account. Unfortunately, this had not been possible in the illustrative application reported in this chapter. In any case, the framework does very well in embedding the research topic, dealing with ecosystem services for watershed management and planning, highlighting how it relates with a general picture of the urban water sector. It thus sets a good background for further analysis of the urban water sector, which I have carried out by considering two different case studies dealing with watershed management for ecosystem services

Chapter 3

Boundary work in adaptive watershed management

3.1 Introduction

This chapter focuses on the role of boundary work in implementing an adaptive watershed management for ecosystem services. Its main objective is to empirically investigate if, how, and to what extent boundary work could facilitate the transfer of knowledge into action in adaptive watershed management. To this end, it investigated an embedded case study, involving a good example of successful transfer of scientific knowledge into action. The selected case study consisted of almost three decades of an adaptive watershed management in the Fuhrberg watershed. The Fuhrberg watershed is the largest contiguous water protection area in Northern Germany. It provides water to roughly 650 thousand people served by Hannover Water Utility (HWU). Boundary work is defined as a set of activities put in place by any organization or individual that seeks to mediate between knowledge and action (Cash et al. 2003). It consists of any effort put in place to manage tension that arises at the interface between stakeholders that have differing views on what represents relevant knowledge (Clark et al. 2011).

The Fuhrberg watershed is characterized by adaptive management that is science-informed and highly participatory for a selected set of ecosystem services, with the HWU as a central actor. This makes the Fuhrberg watershed a particularly informative case study concerning boundary work in practice. The Fuhrberg case study is comparable to several other watersheds in Germany, Europe, and beyond, where similar efforts to establish cooperation between water utilities and land users have been put in place. Examples of this are found in the German cities of Leipzig and Munich, and in the Catskills-Delaware watershed in New York, USA. However, the actors in the Fuhrberg case study can be seen as frontrunners in such efforts that have been built upon several decades of experiences in transdisciplinary research, testing, and development.

Three research questions are addressed in the Fuhrberg watershed case study, namely:

i. What have been critical barriers for the transfer of knowledge into action?
ii. Which boundary work activities have been put in place, and how are they related?
iii. To what extent has boundary work been effective in achieving the theoretical potential for interaction between users and producers of knowledge?

The remainder of this chapter is organized in five parts. First, the theoretical background of boundary work is reviewed. Second, adaptive management in the Fuhrberg watershed is introduced. Third, the research design is described; it consists of four integrative steps: (i) Overall understanding, (ii) Embedded case study design, (iii) Data collection, and (iv) Analysis and generalization. Fourth, the main findings about the case study are presented, including a synthesis of embedding socio-ecological context and the main stakeholders involved in knowledge transfer. Hence, focusing on five most significant boundaries for knowledge transfer, empirical evidence concerning barriers and boundary work activities are presented. Finally, the insights gained from the case study are critically discussed to draw some general conclusions.

3.2 Theoretical background

3.2.1 Attributes, functions and criteria of boundary work

Increasingly, adaptive management is regarded as an effective approach for addressing current socio-ecological issues (Schultz et al. 2015). Its implementation in real-life, however, remains an arduous challenge, because it requires the "linkage of a set of diverse stakeholders and knowledge systems, across different management levels and across sectors" (Kowalski and Jenkins 2015). This challenge has in part been addressed by advancing the concept of bridging organizations (Guston 2001, Folke et al 2005, Olsson et al. 2007, Berkes 2009, Parker and Crona 2012). They consist of a variety of actors that straddle the science-policy interface, aiming to create "an arena of knowledge coproduction, trust building, sense making, learning, vertical and horizontal collaboration and conflict resolution" (Kowalski and Jenkins 2015). Accordingly, the concept of boundary work, which is a subset of the bridging organizations literature, represents a shift of the focus from the organizations to their activities.

Originally, the concept of boundary work served to understand efforts to demarcate "science" from "non-science" (Gieryn 1983). Recently, however, it has been reframed to address an active management of the tension that arises at the interface between user and producers of knowledge (Cash et al. 2003, Clark et al. 2011). According to Cash et al. (2003), boundary work consists of a set of activities put in place by any organization that seeks to mediate between knowledge and action. It includes any effort put in place to manage tension that arises at the interface between stakeholders that have differing views on what represents relevant knowledge (Clark et al. 2011). The consensus is that three attributes of boundary work contribute to the likelihood of success in transferring knowledge into action, namely: participation, accountability, and boundary object (Star and Griesemer 1989, Cash et al. 2003). As Clark et al. (2011) put it, boundary work ought to embrace: (i) meaningful "participation" of stakeholders in agenda setting and knowledge production; (ii) governance arrangements that assure "accountability" to relevant stakeholders; and (iii) production of so-called "boundary objects". A boundary object is a collaborative product (e.g. a report, map, or voluntary agreement), which "is both adaptable to different viewpoints and robust enough to maintain identity across them" (Star and Griesemer 1989). Generally, three functions contribute the most to boundary management, namely, communication, translation, and mediation (Cash et al. 2003). Thus, boundary work ought to include active, iterative, and inclusive communication, compounded by a translation of concepts to facilitate mutual understanding, as well as by efforts of mediation, to resolve potential conflicts (Cash et al. 2003). Such functions, in turn, often require efforts of capacity building aimed at empowering stakeholders (Cash et al. 2003, Kristjanson et al. 2009, Clark et al. 2011). Most importantly, Cash et al. (2003) identified three criteria that determine the effectiveness of boundary work, namely, "credibility", "saliency", and "legitimacy". Thus, boundary work effectiveness depends on the extent to which stakeholders perceive it as being technically adequate in the handling of evidence (i.e., credible), relevant to the problem at hand (i.e., salient), and fair, unbiased, and respectful of all stakeholders (i.e., legitimate) (Cash et al. 2003, Mitchell et al. 2006, Clark et al. 2011).

3.2.2 A generalized framework of boundary work

Until recently, a major shortcoming of the boundary work concept had dealt with its level of generalizability (Clark et al. 2011). In fact, it had mainly relied on empirical evidences from the Global North. Clark and colleagues addressed this shortcoming by analyzing several decades of research in the Global South (Clark et al. 2011). They collected empirical evidences of knowledge transfer involving the Consortium of International Agricultural Research Centers (CGIAR). Interestingly, their research confirmed that there was an even richer variety of boundary work being carried out. Their findings suggested that boundary work strategies could be best captured as a dual response to the different uses, and sources of knowledge. Therefore, they have advanced and produced a generalized framework for characterizing boundary work based on use (U) and source (S) of knowledge (see Figure 3.1). More specifically, Clark et al. (2011) proposed a matrix for classifying boundary work based on three types of knowledge uses, and three types of knowledge sources, resulting in nine possible combinations. In terms of use, knowledge can generally contribute to enlightenment (A. Enlightenment - Uo), or specifically support decision-making by either a single (B. Decision - U1) or multiple users (C. Negotiation - Um). In terms of source, users may perceive knowledge as originating from themselves (Personal expertise - S0), a single community of expertise (Single community of expertise - S1), or multiple and potentially conflicting communities of expertise (Multiple communities of expertise - Sn).

BOUNDARY WORK		**USE of knowledge to support...**		
		A. Enlightenment (U0)	**B. Decision (U1)**	**C. Negotiation (Um)**
		CREDIBILITY	CREDIBILITY + SALIENCY	CREDIBILITY+SALIENCY+LEGITIMACY
SOURCE of knowledge...	**Personal expertise (S0)**	$S_o \leftrightarrow U_o$ *Contemplation*	$S_i \leftrightarrow U_j$ *Decision*	$S_i \leftrightarrow \begin{matrix} U_k \\ \updownarrow \\ U_\ell \end{matrix}$ *Politics*
	Single community of expertise (S1)	$S_1 \leftrightarrow U_o$ *Demarcation* A.2	$S_i \leftrightarrow U_j$ *Expert advice* B.1 B.2	$S_i \leftrightarrow \begin{matrix} U_k \\ \updownarrow \\ U_\ell \end{matrix}$ *Assessment* C.1
	Multiple communities of expertise (Sn)	$\begin{matrix} S_i \\ \updownarrow \\ S_j \end{matrix} \leftrightarrow U_o$ *Integrative R&D* A.1	$\begin{matrix} S_i \\ \updownarrow \\ S_j \end{matrix} \leftrightarrow U_j$ *Participatory R&D*	$\begin{matrix} S_i \\ \updownarrow \\ S_j \end{matrix} \leftrightarrow \begin{matrix} U_k \\ \updownarrow \\ U_\ell \end{matrix}$ *Political bargaining*

Figure 3.1: Generalized framework of boundary work by Clark et al. 2011, including five illustrative boundaries investigated in the Fuhrberg watershed case study (A.1, A.2, B.1, B.2, and C.1)

For each combination, Clark et al. (2011) defined the criteria and strategy that contributed to effective boundary work. They argued that the former primarily depended on the use of knowledge. Hence, in the case of knowledge use for enlightenment (Uo), boundary work should ensure credibility only, while for decision-making (U1), both credibility and saliency have to be achieved. Similarly, for negotiation (Um), boundary work should jointly consider and mange tradeoffs between credibility, saliency, and legitimacy. Boundary work strategies, on the other hand, consisted of highly context specific strategies that depend on both why knowledge is used and how its source is perceived. Altogether, Clark et al. (2011) identified nine broad strategies, which they label as: Contemplation, Decision, Politics, Demarcation, Integrative R&D, Expert Advice, Participatory R&D, Assessment, and Political Bargaining. They spanned from the simplest, i.e. Contemplation, which is to be adopted when knowledge is used for enlightenment and stakeholders perceive such knowledge as their own, to the most challenging case, i.e. Political bargaining, which is more appropriate when diverse stakeholders with divergent interests use knowledge from multiple and potentially conflicting sources for negotiation purposes. Moreover, Clark et al. (2011) presented examples of barriers and boundary work strategies, based on empirical evidence from several decades of transdisciplinary research by CGIAR.

The framework proposed by Clark et al. (2011) is a powerful tool for exploring the theoretical potential for interaction among users and sources of knowledge. As it can be compiled with empirical data, it can be used either to assess boundary work that has actually been deployed or to identify strategies for facilitating knowledge transfer (Clark et al. 2011). So far, only parts of the framework have been used in the analysis of diverse policy issues, including the effectiveness of participatory scenario development (Chaudhury et al. 2012), and the role of boundary organizations (Boezeman et al. 2013). Despite its strength, the framework has yet to be applied to analyze a historic evolution of knowledge to action transfer. Moreover, based on a review of 22 papers citing Clark et al. (2011), I found no empirical study that considered the whole process of the transfer of knowledge, to investigate the linkage of set of diverse stakeholders and knowledge systems, across management levels and across institutional boundaries (Kowalski and Jenkins 2015). In particular, no study investigated boundary work as a dynamic process that takes place within a “Landscape of Tensions” (Parker and Corona 2012) and with high empirical resolution. As shown in Figure 3.2, the Landscape of Tension is an attempt of conceptualizing the multi-dimensional and dynamic nature of boundary organizations and boundary work proposed in Parker and Corona (2012). It highlights that boundary work is not a single-time achievement; rather is part of a dynamic process involving different types of tensions at the interface between stakeholders engaged in knowledge transfer. As shown in Figure 3.2, these include tension between “basic versus applied research”, “disciplinary versus interdisciplinary”, “long-term versus real-time”, and “autonomy versus consultancy” (Parker and Corona, 2012). Interestingly, Parker and Corona (2012) put emphasis of the fact that boundary work has to deal with the fact that demands of some stakeholders may be simply incommensurable.

Therefore, given this conceptual foundation presented in this section, I analyzed the embedded case study (Yin 2008) of three decades of effective, science-informed, and participatory adaptive watershed management in the Fuhrberg watershed, investigating boundary work as part of a dynamic process that takes place in a “Landscape of Tensions”, rather than a single-time achievement (Parker and Corona 2012).

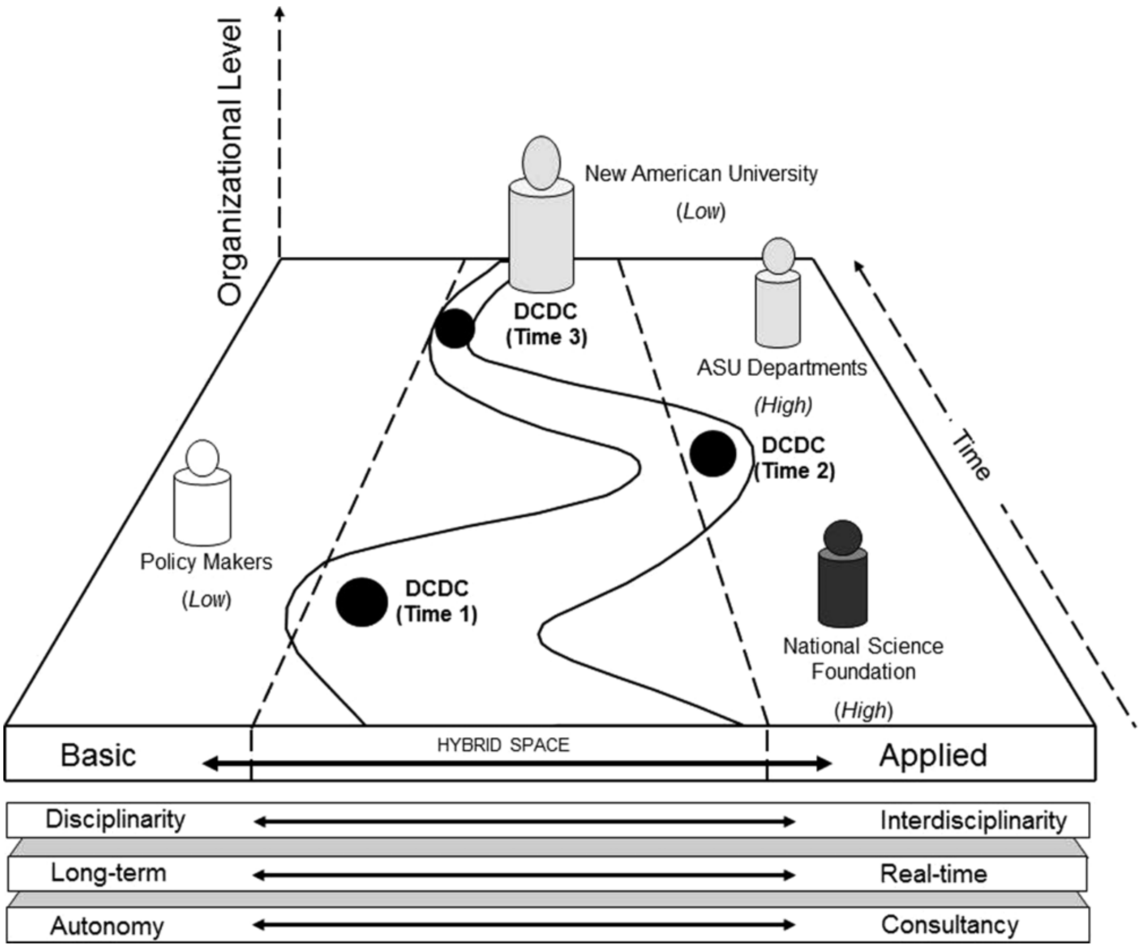


Figure 3.2: "Landscape of Tension" a conceptual framework highlighting the multi-dimensional and dynamic nature of boundary work, involving diverse stakeholders and their at times incommensurable demands (source: Parker and Corona 2012).

3.3 Analysis of the case study

In the following part, I introduced HWU and the adaptive management in the Fuhrberg watershed, highlighting their significance for investigating the practice of boundary work.

3.3.1 Hannover Water Utility and the Fuhrberg Watershed

HWU supplies drinking water to around 650 thousand people in Lower Saxony's capital city, Hannover, and five surrounding districts (see Figure 3.3). It started in 1878 with a single waterworks, supplying 900 households and a single factory. Today, it serves 90.000 connections, delivering around 40 million cubic meters of drinking water yearly. HWU has around 70 employees, with an average working age of 19 years, and an annual sales revenue of 70 million Euros (Enercity, 2011). From an infrastructural perspective, HWU runs three waterworks (i.e. Fuhrberg, Elze-Berkhof, and Grasdorf - see Figure 3.3 and Table 3.1), a long network (i.e. 2200 Km of feeders, mains and distribution pipes, and 1250 Km of house connections), and several elevated tanks and booster systems, which collectively guarantee delivery of high-level water services.

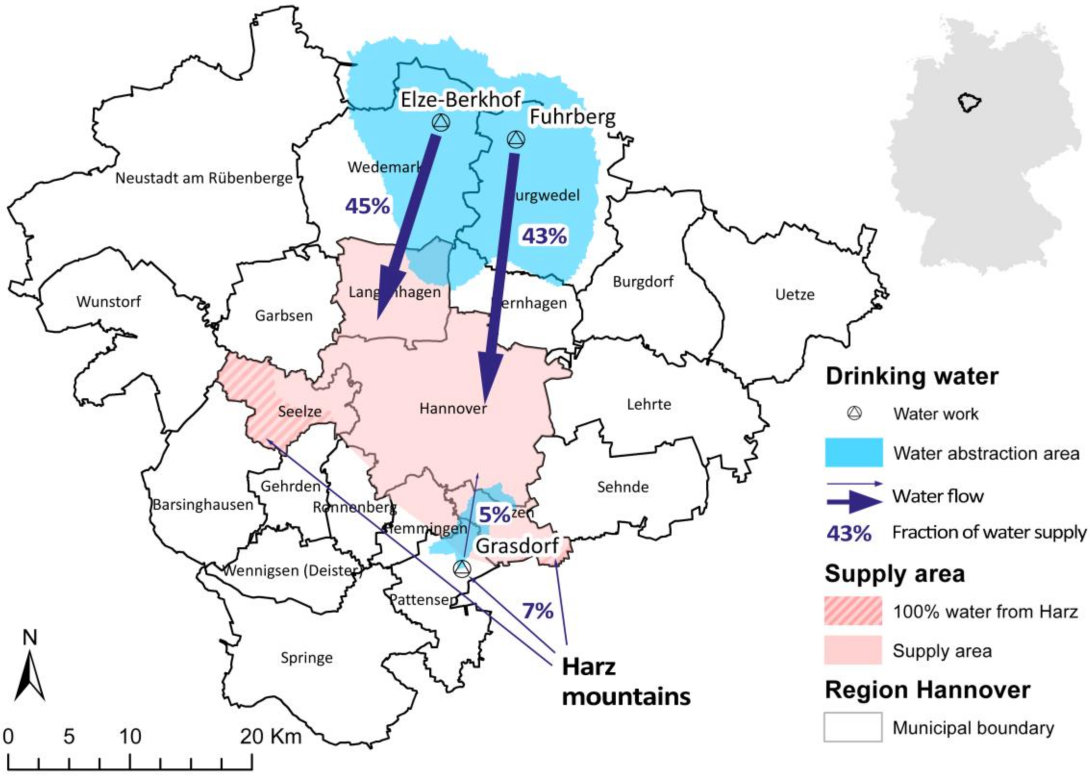


Figure 3.3: The water supply system managed by Hannover Water Utility and its role in linking areas of ecosystem service production and benefit.

In terms of water resources, HWU relies almost entirely on groundwater extracted from 106 wells, of which 90 are located in the Fuhrberg watershed (also known as “Fuhrberger Feld”), and 16 in Grasdorf, a much smaller watershed to the south of Hannover. The Fuhrberg watershed is a region located 30 km to the northeast of Hannover and is the largest contiguous water protection area in Northern Germany. It supplies 87% of the water distributed by HWU; the remaining 13% is groundwater from the Grasdorf watershed, which is enriched with water from the Leine River and dam water from the Harz Mountains.

Table 3.1: The water supply system managed by Hannover Water Utility, focus on infrastructures (source: Enercity 2011a, 2011b).

HWU waterworks	Grasdorf	Fuhrberg	Elze-berkhof
Commissioning year	1899	1959	1968
Delivery as % of network area	~ 5%	~ 43%	~ 45%
Peak output	12,000 m^3/day	85,000 m^3/day	85,000 m^3/day
Watershed name	Grasdorf	Fuhrberg	Fuhrberg
Watershed area	27 km²	300 km²	300 km²
Water production			
Vertical wells	9 with 100 m^3/h	-	81 with 60-90 m^3/h
Horizontal wells	7 with 85-170 m^3/h	5 with 800 m^3/h	4 with 400-600 m^3/h

As shown in Figure 3.4, land use in the Fuhrberg watershed is roughly 43% agriculture (i.e. 13.262 ha), 42% forestry (i.e. 12.745 ha), and the remaining 15% (i.e. 4.770 ha) includes settlements, transport infrastructure, and other. The Fuhrberg is sub-divided in three distinct zones (Zone I, II, and II), characterized by different protection levels as well as land use distributions, which will be discussed later on. From an ecosystem service perspective, the Fuhrberg watershed is an important service production area, providing several goods and services, including water provision and purification, food production, and biodiversity conservation (von Haaren and Bathke, 2008).

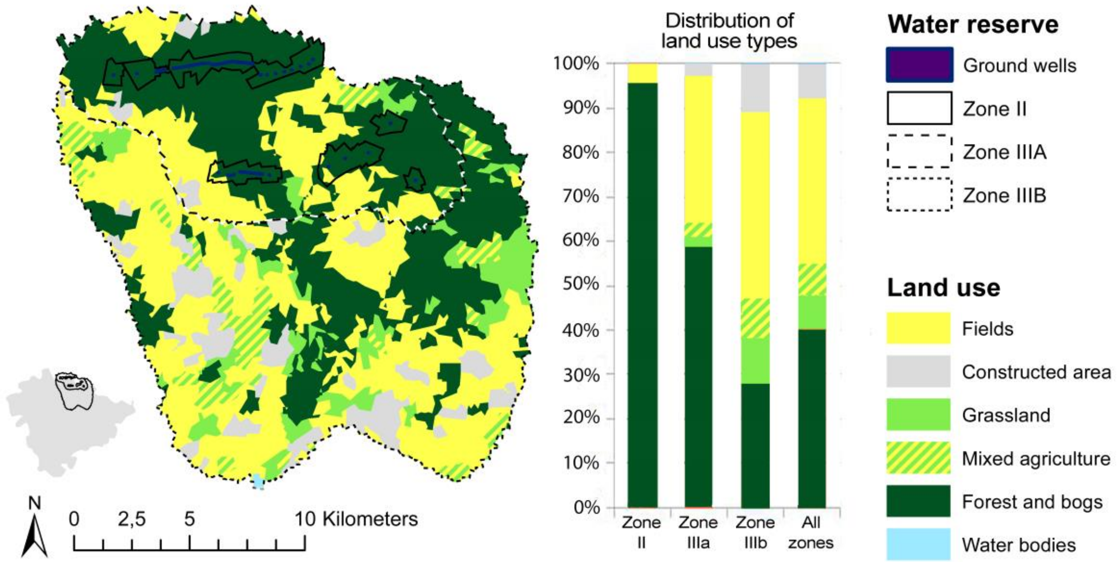


Figure 3.4: Land use distribution in the Fuhrberg watershed and the three water protection levels (Zone I-wells, II, and III).

3.3.2 Significance of the Fuhrberg case study for exploring boundary work

Since the late 1970s, HWU has been a central actor within a process that, in hindsight, can be regarded as a good example of adaptive watershed management. From the beginning, HWU was involved in an important scientific research project, which resulted in better understanding of the determinants of groundwater resources and several peer-reviewed papers, published in international journals. Interestingly, HWU has been effectively promoting the transfer of such new scientific knowledge into action. Initially, it was the sole promoter of science-based safeguarding measures to protect groundwater in the Fuhrberg watershed; its initiatives ranged from acquisition of more land, to experimental collaboration with farmers. Over time, HWU's engagement with farmers and other stakeholders became prevalent and more systematic, ultimately resulting in a network of actors responsive to water challenges both locally and further afield. Among other things, in the late 1980s, HWU launched an extension service to promote groundwater friendly agriculture by advising willing land users. This was followed by formal mechanisms of collaborative implementation of groundwater protection, including the so-called "drinking water co-operation" (MU Niedersachsen, 2002, cited in Kastens and Newig, 2007) and "area co-operation" (MU Niedersachsen, 2005, p. 2 cited in Kastens and Newig, 2007). As will be described later on, both mechanisms consisted of local working groups involving diverse stakeholders engaged in water protection and nature conservation. Further steps that aim to raise general public awareness, and at the same time improve HWU's corporate image, include initiatives such as "Grasdorf water trails" (since 1994), and "Fuhrberg Water Adventure Path" (since 2003).

From a boundary work perspective, the case of the Fuhrberg watershed management is highly informative because of the long-term and close interactions in knowledge use and production, at both individual and organizational levels. Actors involved in the process include scientists, water managers, farmers, landscape planners, local authorities, and environmental groups. Of particular interest is an interplay of temporal scales, which allows exploration of different stakeholder's views and their implications in terms of boundary work. Thus, it allows investigating knowledge use and production in watershed management for selected ecosystem services, in particular for water provision and quality regulation. To add focus, I considered the two main biochemical processes that determine groundwater quality in the Fuhrberg watershed: "denitrification" and "desulfurication" (see Box 3.1). These are two highly interlinked processes, but at the same time, are characterized by different reaction kinetics (e.g. half-lives of 2-4 years and 70-100 years, respectively). Above all, the two processes depend on fertilizer input, or more generally, on agricultural practices and historical land use conversion. These are all crucial aspects in region such as Lower Saxony, known as the "German Silicon Valley of agricultural industry" (Windhorst, 2000, p. 4, as cited in Kastens and Newig, 2007). Noteworthy is the fact that private actors made substantial investments in the Fuhrberg watershed, with HWU being the principal investor. Their interests, however, tended to be biased towards certain ecosystem services and a logic of short-term returns, which means that long-term goals such as biodiversity and nature conservation are potentially overlooked. In addition, a significant reduction in the demand for urban water calls for a rethinking of the water supply system to ensure its long-term financial sustainability (Enercity 2011a, 2011b). This long-term trend is in line with the general situation in Germany, where water consumption has decreased significantly in the last 20 years, mainly due to higher water efficiencies, altered consumer behaviors and demographic changes (Bundesverband der deutschen Energie- und Wasserwirtschaft, 2010). Finally, as part of the Hannover Public Utility, HWU is engaged in several global issues, including adaptation and mitigation of climate change, and reduction of virtual water consumption. Perhaps, Hannover Public Utility is the most important of some 80 partners of the "Climate Alliance Hannover 2020", aiming at a 40% reduction in CO_2 emissions.

Therefore, the establishment and implementation of an effective, science-informed, and highly participatory adaptive watershed management for in the Fuhrberg watershed, is highly pertinent for the objectives of this research. In particular, direct access to professional and personal experiences of key informants involved in the case study, and the availability of documentary sources, makes the Fuhrberg watershed case study ideal for an empirical investigation of boundary work.

In the following part, I described the evolution of the Fuhrberg watershed management, putting emphasis on specific scientific findings of a research project on groundwater quality, and their implications for planning and management.

3.3.3 Scientific research and implementation in the Fuhrberg watershed

Throughout the 1960s, 70s, and 80s, water abstraction had been a cause of disagreement between HWU and farmers in the Fuhrberg watershed. Lowering of water table due to abstraction was believed to harm the income of farmers, who were thus compensated by HWU. Monetary compensation was based on impacts simulated by a biophysical model, which had been developed ad hoc by HWU. At the same time, throughout the 1960s and 70s, groundwater in the Fuhrberg watershed had been characterized by a gradual deterioration of its quality (Figure 3.5). For instance, in the late 1970s, sulfate concentration (blue line) had reached a threshold value of 250 mg/l (dotted blue line), while nitrate concentration (red line) remained far below 50 mg/l. These levels were the main stimulus for HWU to take part in a research project, aiming to gain a better scientific understanding of the determinants of groundwater quality in the Fuhrberg watershed. The research, carried out in partnership with the Federal Research Institute of Soil Sciences in Hannover (FRISSH), produced a detailed understanding of biochemical processes that determine water quality in the aquifer. Among other things, it identified two distinct zones of "denitrification" and "desulfurication" in the aquifer, the role of nitrate leaching from different land uses, and the impact of historical land use changes (See Box 3.1 for details). For instance, the research showed how two rounds of conversion of grassland to arable land were the main cause of increase in sulfate concentrations (see green bars in Figure 3.5). The first round of grassland conversion took place during 1960-1968, following the lowering of the groundwater table due to water abstraction by HWU. The second conversion took place during 1975-1982, partially due to changes in EU agricultural subsidies. The research revealed how grassland conversion had caused high nitrate leaching (more than double), due to mineralization of organic soil nitrogen during the 2-4 years after plowing. This extra input of nitrate had been "denitrified" in the aquifer, resulting in a higher sulfate concentration in groundwater (i.e. the main challenge for HWU).

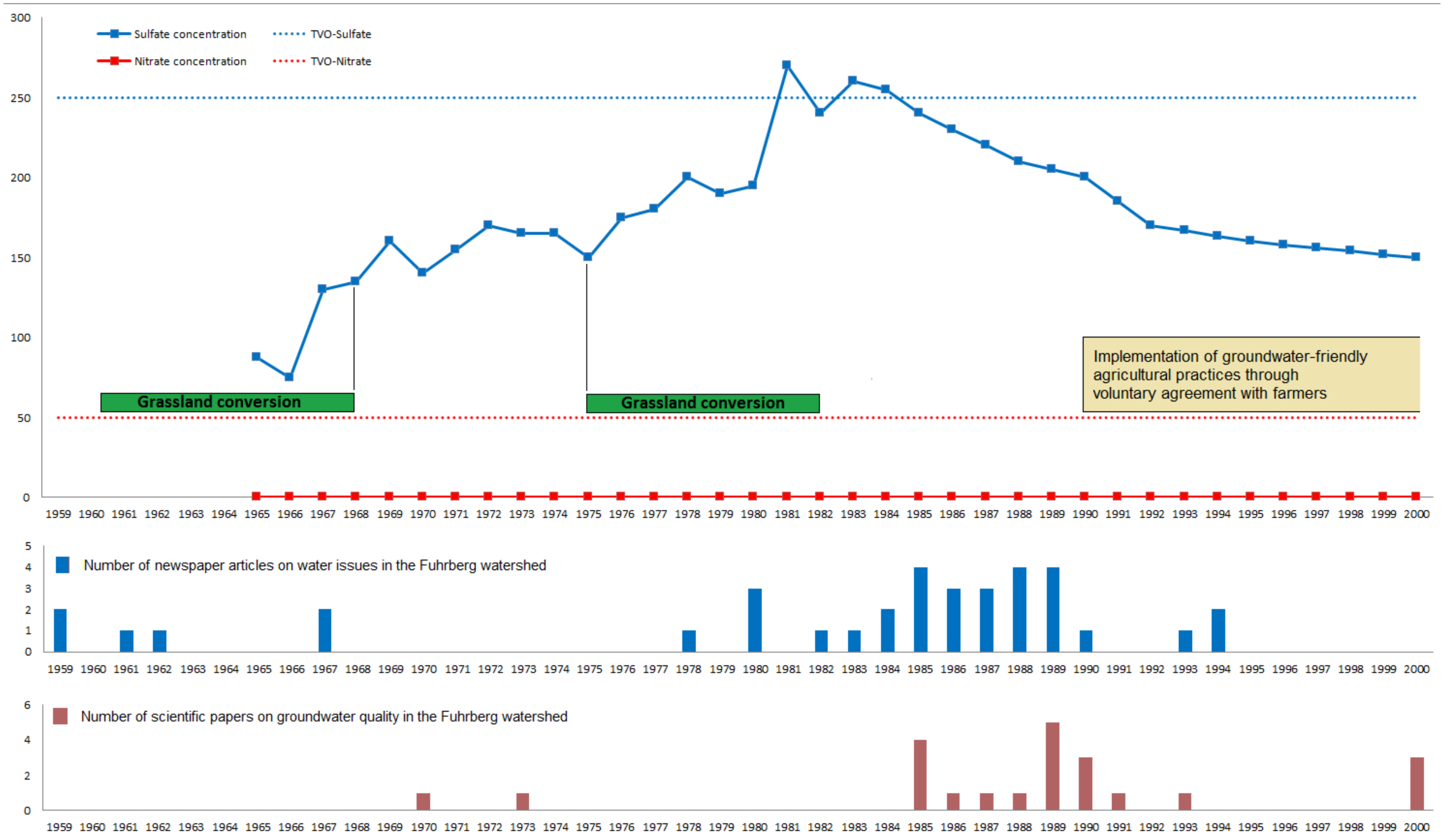
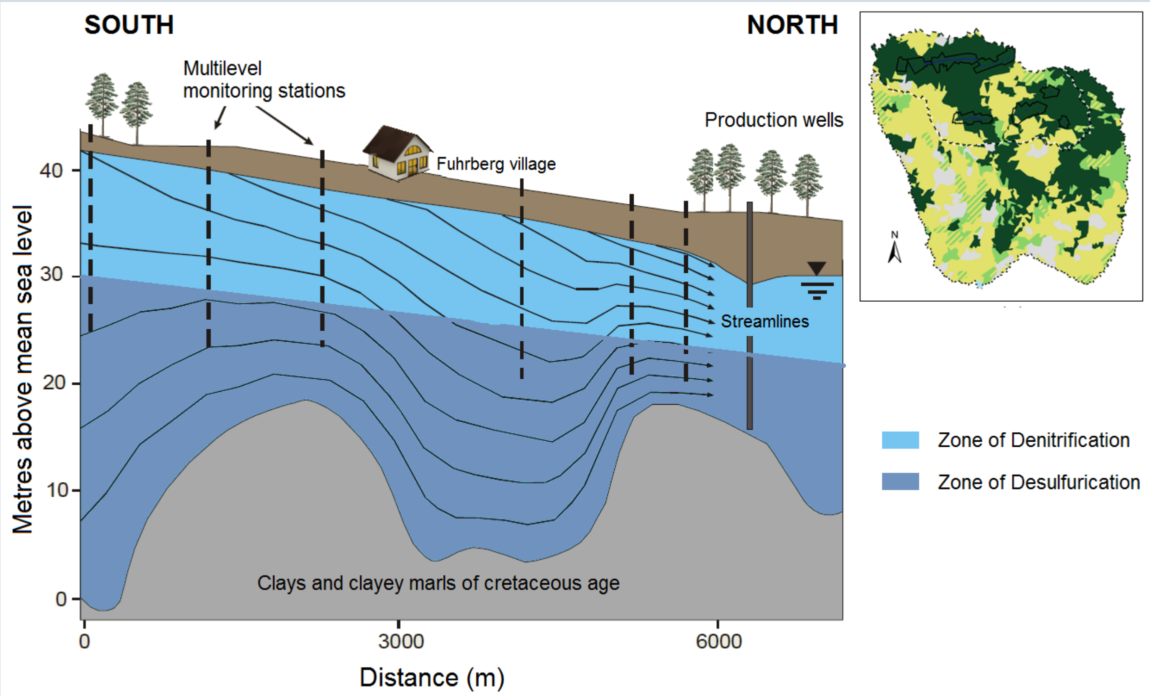


Figure 3.5: Trends in the Fuhrberg watershed management expressed in terms of: (i) groundwater quality and its relation with conversion of grassland to arable land (green bars) and the subsequent involvement of the farmers (yellow bar), (ii) number of newspaper articles about Fuhrberg watershed, and (iii) number of scientific articles dealing with determinants of groundwater quality in the Fuhrberg watershed.

SCIENTIFIC FINDINGS ON GROUNDWATER QUALITY IN FUHRBERG

Water source in the Fuhrberg is a sandy clayish, 20-30 meters deep unconfined aquifer (Lillich et al., 1973). During the 1980s, the joint scientific research, carried out by HWU and FRISSH, has clearly identified the determinants of groundwater resources in the Fuhrberg watershed.
Among other things, it discovered two distinct layers within the aquifer, characterized by two different processes. An “upper groundwater portion”, where nitrate is removed and sulfate is formed due to microbial activity that uses particles of reduced sulfur compounds as electron donors (Kölle et al., 1985); and a “lower groundwater portion”, where sulfate formed in the upper layers is microbially reduced, using mainly organic carbon as energy source



South-North cross-sectional view through the aquifer, and the main biochemical processes in the Fuhrberg watershed (Adapted from original by Prof. Dr. Jürgen Böttcher of LUH)

The two processes (i.e. “denitrification” in the upper part, and “desulfurication” in the lower) are characterized by different reaction kinetics; their half-life (i.e. amount of time required for a quantity to fall to half its starting value) is of 1-2.3 years and 70-100 years, respectively. Such reaction kinetics, however, refer to an ideal conditions, in which all the needed components are available. In the case of denitrification, for instance, if the supply of reduced sulfur components (produced in the lower part and not in the upper) is gradually depleted, the reaction kinetics slows down and eventually approaches zero (Boettcher et al., 1985, 1989). This is actually the case; in fact, reduced sulfur is mainly produced in the lower part and is much slower. In turn, this would mean a collapse of the whole system, and breakthrough of nitrates in the extraction wells. Consequently, it was understood the importance and need of reducing the input of nitrates to the system, so as to limiting the rate of depletion of reduced sulfur components in the aquifer. This is indeed the guiding principle behind the groundwater protection in the Fuhrberg.

Box 3.1: Synthesis of scientific findings concerning two biochemical processes that determine groundwater quality in the Fuhrberg watershed (source: Notes by Prof. Dr. Jürgen Böttcher of the Leibniz University of Hannover).

Today, the abovementioned scientific findings form the basis of the adaptive watershed management for ecosystem services in the Fuhrberg watershed. According to HWU's management, four implementation strategies currently characterize the Fuhrberg watershed management (see Table 3.2). These strategies stem from a better scientific understanding of the biochemical processes in the Fuhrberg watershed. Nevertheless, they can be considered an emergent outcome of decades of real-life experimentation by HWU. As such, they reflect numerous and complex interactions among stakeholders engaged in knowledge use and production. These interactions form the object of the following empirical inquiry.

Table 3.2: Four strategies adopted by Hannover Water Utility to implement an adaptive management in the Fuhrberg watershed (source: Enercity management).

Strategy	Description
Agriculture	Control pollutant input, in particular promote extensification measures, through voluntary agreements with farmers.
Forestry	Optimize forest management to improve quality and quantity of groundwater recharge (for e.g. nitrogen leaching from forest is 4 mg/l, against 88.9 mg/l from fields and grasslands). This includes converting coniferous forests to deciduous.
Water management	Implement measures for controlling runoff, especially through naturalization of canals. Optimize operation of abstraction wells.
Watershed area management	Collect surface unit data, and combine these data to predict the impact of interventions on the land use system, both soil and groundwater.

3.4 Methods

In this chapter, the four steps of the research design shown in Table 3.3 are described.

Table 3.3: Four integrative steps of the research design.

Methodological step	Description
Overall understanding	- Review of documentation - Guided conversation with experts - Analysis of stakeholders engaged in knowledge transfer - Identification and classification of boundaries
Embedded case study design	- Definition of spatial and temporal limits of the case study - Definition of sub-units of analysis - Data need analysis and identification of sources - Characterization of socio-ecological context
Data collection	- Formulation and testing of questionnaires - Semi-structured interviews, workshop, and field visits - Full transcription and synthesis
Analysis and generalization	- Compilation of boundary work matrix (Clark et al. 2011) - Assessment of empirical evidence of boundary work - Triangulation and generalization

3.4.1 Overall understanding

Different types of documents were reviewed, including scientific papers dealing with determinants of groundwater quality in the Fuhrberg watershed, local newspaper clippings, and public and internal reports prepared by HWU. Further focus on the process of knowledge transfer was gained through guided conversations with primary sources. The interviews mainly covered how the partnership between HWU and FRISSH started and how it developed over time, and the implications of the new scientific findings for management in the Fuhrberg watershed. Subsequently, based on their contribution to the adaptive watershed management in the Fuhrberg watershed, some key stakeholders as well as a set of five illustrative boundaries were identified.

The stakeholders are illustrative of different types of knowledge users and producers, across management levels and sectors (Kowalki and Jenkins, 2015). Similarly, the five boundaries are illustrative of different types of tension that arises at the interface between stakeholders, possibly representing a whole "landscape of tension" (Parker and Corona, 2012). In particular, the five boundaries were tentatively classified based on the general framework by Clark et al. (2011) and labelled as A.1, A.2, B.1, B.2 and C.1 (See Figure 3.1). Among other things, this allowed defining, for each boundary, a theoretical potential for interaction between stakeholders involved in knowledge use and production (e.g. by identifying the most appropriate boundary work criteria and strategies). Having gained an overall understanding, an embedded case study (Yin 2008) was designed to further investigate the Fuhrberg watershed management, in search of empirical evidence of boundary work.

3.4.2 Embedded case study design

3.4.2.1 Spatial and temporal limits, and sub-units of analysis

As shown in Figure 3.6, the embedded case study was conceived as an ongoing process of transfer of scientific knowledge into action, identifying its four most crucial stages. Broadly, I considered: (i) late 1970s, beginning of joint research project between HWU and FRISSH; (ii) late 1980s, decision by HWU to launch an advisory extension service for farmers; (iii) early 1990s, start of voluntary agreements with farmers to implement groundwater protection measures; and (iv) early 2000s, inclusion of biodiversity and nature conservation objectives, through a participatory landscape planning processes.

Shown in Figure 3.6 are the four stakeholders, used as sub-units for analysis in the embedded case study. They were identified based on the extent that they have affected the process of knowledge transfer and their contribution to adaptive watershed management in the Fuhrberg watershed. They represent the stakeholders typically involved in adaptive watershed management. For both clarity and generality, the four sub-units were labelled as the “Scientific community”, “Water utility”, “Farmers’ community”, and “Landscape planning”. Following are some specification about the stakeholders in the Fuhrberg watershed.

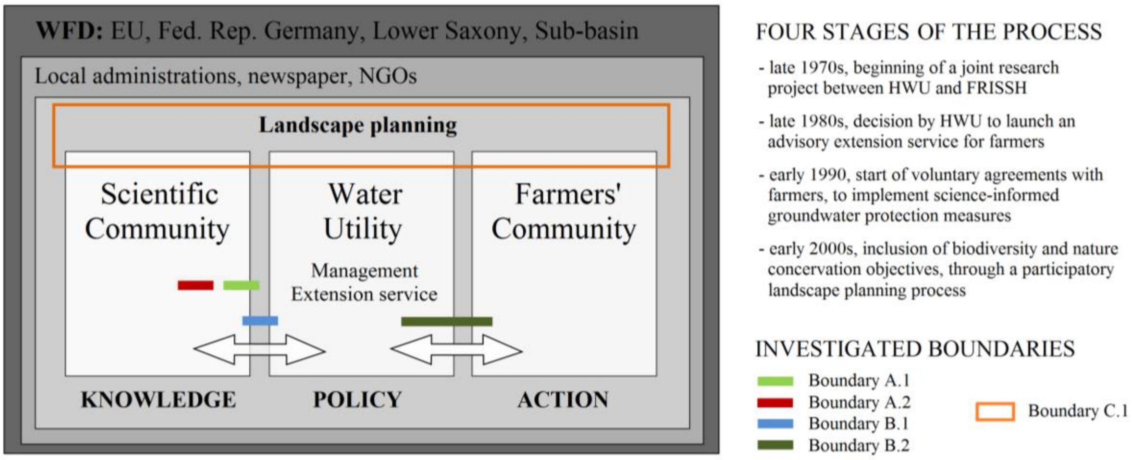


Figure 3.6: Embedded case study representing transfer of knowledge into action in the Fuhrberg watershed management, highlight of the four stages of the process and the five most significant boundaries considered for empirical investigation.

The Scientific community comprised the then head of HWU’s water laboratories and the soil scientists from FRISSH. During 1980-1985, this group jointly applied for funding and carried out extensive scientific research, which led to a detailed understanding of the biochemical processes that determine groundwater quality and quantity in the Fuhrberg watershed. Water utility refers to HWU and its advisory extension service, whose primary purpose was to promote groundwater protection, through voluntary agreements with farmers. HWU is part of Hannover Public Utility (i.e. “Enercity” or in German “Stadtwerke Hannover AG”*)*, a long-lived institution that provides electricity, gas, and district heating. Since 1971, Hannover Public Utility has become a joint-stock company owned by the city of Hannover. Today, with close to 2600 employees and an annual revenue of almost two billion Euros, it is one of the largest companies in Germany (Enercity 2011a). Due to HWU’s organizational autonomy, however, in this study Hannover Public Utility was considered only as part of the embedding context. Instead, the focus was on HWU and its proactive involvement in scientific research projects; particularly, on how it succeeded in integrating new scientific findings in its systems of watershed management and decision-making. To this end, it was found it useful to distinguish between “Management” and “Extension service”. The Farmers’ community includes nearly 200 agricultural holdings that today cover more than 13.000 ha, roughly 43% of the Fuhrberg watershed. In fact, despite the initially strained relations between HWU and farmers (i.e. during 1960s-1990s), today, 70% of the agricultural land is covered by voluntary agreements of groundwater protection management. Finally, Landscape planning consists of both involved experts and the approach of landscape planning. The former were landscape planners from the Institute of Environmental Planning in Hannover ("Institut für Umweltplanung" - IUP) at the Leibniz University of Hanover. They had been invited by HWU to take over the coordination of the abovementioned "drinking area co-operations", which at that time had failed in fully meeting their initial expectations.

In the above described embedded case study design, two aspects need further clarification. Firstly, the fact that the four sub-units of analysis are not the only stakeholders in the process of knowledge transfer in the case study. Indeed, given the relatively long time-period and scale of our analysis, there were also other stakeholders, including residents and civil society organizations. However, their impact on the process of knowledge transfer investigated here had been indirect or relatively limited. Therefore, they were included only as part of the embedding context. Secondly, the fact those three sub-units of the analysis were arguably associated with three different stages of the process of knowledge transfer in the Fuhrberg. More specifically, (i) production of scientific knowledge - Knowledge, (ii) translation into policy and decisions - Policy, and finally (iii) implementation on the ground – Action, were associated to "Scientific Community", "Water Utility" and "Farmers' Community" respectively, while landscape planning went across the three stages (Figure 3.6). However, it is worth clarifying that what may appear in the scheme as a linear flow of knowledge was only a helpful frame for analyzing the phenomenon over time. Generally, the sub-unit as well as the embedding socio-ecological context feedback to each other.

3.4.2.2 Embedding socio-ecological context

Diverse factors affected to different extents the process of knowledge transfer in the case study, including the regulatory framework, the relative influence of actors, the main societal concerns, and the historic pathways. Accordingly, literature addressing relevant issues, such as implementation of the Water Framework Directive (WFD) in Lower Saxony, integrated landscape planning in the Fuhrberg watershed, and evolution of metropolitan governance in Hannover Region was analyzed. Moreover, content analysis of newspaper articles about the Fuhrberg watershed, since the start of water abstraction in the mid-1950s, was performed. Arguably, newspapers were regarded as a reliable proxy of the general societal concerns, especially when covering such a long time-period. Among other things, they allowed gaining an overall understanding of trends: water-related stakeholders' interactions and level of societal awareness (see Figure 3.5).

3.4.2.3 Data collection: interviews, workshop, and field

Three interview protocols were designed in order to cover the five representative boundaries and stakeholders engaged in knowledge use and production (see

Table **3.4**). Semi-structured interview questions were used to address relevant issues, including the organizational structure of HWU, critical moments in the implementation of an adaptive watershed management (for e.g. beginning of the joint-scientific research, decision regarding installment of a treatment plant, acquisition of land and launching of advisory service), and interaction between stakeholders. The questionnaires were designed according to Harrell and Bradley (2009) and administered to other researches as a pre-test. (See Appendix 2).

The questionnaires were used to interview both primary and secondary sources with several years of direct involvement in the case study (Scholz and Tietje, 2002). Interviewees were selected in a purposive and snowball fashion (Bryman, 2001), to cover all sub-units of analysis, at different phases of the process of knowledge transfer. It was made sure to include "numerous and highly knowledgeable informants, who view the focal phenomena from diverse perspectives" (Eisenhardt and Graebner 2007).

Table 3.4: Topics addressed to investigate the five most significant boundaries for knowledge into action transfer in the Fuhrberg watershed management case study (A.1, A.2, B.1, B.2 and C.1).

Questionnaire A **Farmers**	**Questionnaire B** **Water managers**	**Questionnaire C** **Landscape planners**
• Involvement with HWU • Main driver for cooperation • Advantages and disadvantages of cooperation • Learning from cooperation	• Introduction to HWU and the advisory extension service • Decision about water treatment plant (1985) • Role of the then head of HWU's water laboratory • Negotiation for abstraction rights (1980s-90s) • Land acquisition (late 1980s) • Cooperation with Farmers (1988-90s) • Scaling Up and/or Replication of the Fuhrberg experience (today)	• Farmers perception of previous collaboration with HWU (-2000) • Participatory planning process to integrate water protection with nature and biodiversity conservation, and agricultural production (2003)

Nine interviews, a focus group and a field visit were conducted during June-November, 2014. The focus group, in particular, involved three senior water managers from HWU and a knowledgeable M.Sc. student from the IUP. The workshop, which had been facilitated by an expert landscape planner and myself, aimed at getting a closer look at HWU's decision-making processes and their implications from a boundary work perspective. All the interviews and workshops have been recorded, hence, transcribed using software f4 ©.

3.4.2.4 Analysis and generalization: synthesis and triangulation of findings

Data from the interviews and the workshop was triangulated with other documentary sources. Hence, the empirical evidence of boundary work was characterized based on "Barriers" and the boundary work attributes of "Participation", "Accountability" and "Boundary object". In the analysis, the context (i.e. use and source of knowledge) was considered as an independent variable, and empirical evidence of boundary work as the dependent variable. Thus, the empirical evidences were assessed against the theoretical potential for interaction among users and producers of knowledge, in accordance with the framework by Clark et al. (2011). Finally, the case study findings were critically discussed to proceed with an analytical generalization (Yin 2008). Noteworthy was how, to further enhance the construct validity of the research (Yin, 2008), three key informants (all professors) were asked to review the draft of this chapter, and hence their comments were duly integrated.

3.5 Results

This section is organized in three parts. Firstly, the key informants, which are representative of the main stakeholders involved in knowledge use and production in the Fuhrberg case study, are introduced (3.5.1). Secondly, the findings about the embedding socio-ecological context are presented, including the implementation of the Water Framework Directive in Lower Saxony and content analysis of local newspaper articles (3.5.2). Thirdly, an account of the empirical evidences of boundary work is provided (3.5.3). For the five illustrative boundaries, the main barriers to knowledge transfer and boundary work put in place to overcome them are described, specifying the attributes of participation, accountability and boundary object. Here, the results were presented in a narrative format instead of tables, to give an idea of the dynamic process in which boundary work took place.

3.5.1 Users and producers of knowledge in Fuhrberg watershed

The main stakeholders engaged in knowledge use and production in the case study were those selected as our units of analysis, i.e. Scientific community, Water utility, Farmers' community, and Landscape Planning. Shown in Table 3.5 are the key informants interviewed to empirically investigate boundary work and the rationale for their involvement. The selection of informants was representative of the main stakeholders and five representative boundaries in the case study.

Table 3.5: Key informants and the rationale behind their involvement.

Interviewee	Source	Sub-unit	Type	Rationale for involvement
Farmer 1	Primary	Farmers' community	Semi-structured	Speakers of the farmers community, involved since the beginning of intense cooperation in the 1980's. Has been initially contacted by the utility (Quest. A)
Farmer 2	Secondary	Farmers' community	Semi-structured	Joined following his father and some friends who were already part of the cooperation (Quest. A)
Farmer 3	Secondary	Farmers' community	Semi-structured	Part of the cooperation. (Quest. A)
Farmer 4	Secondary	Farmers' community	Semi-structured	Part of the cooperation. (Quest. A)
Scientist 1*	Primary	Scientific community	Unstructured	Soil scientist from the Federal Research Institute, involved in the joint research in Fuhrberg since 1983. Currently a professor of Soil Sciences at LUH (Quest. B)
Scientist 1	Primary	Scientific community	Semi-structured	See above
Manager 1	Primary	Water utility	Semi-structured	Former-head of the extension service from 1989-1997. Currently a professor of Soil Science at Osnabrück University of Applied Sciences. (Quest. B)
Manager 2	Primary	Water utility	Workshop	Head of Hannover Water Utility (Quest. B)
Manager 3	Primary	Water utility	Workshop	Field water management and technician at Hannover Water Utility (Quest. B)
Manager 4	Primary	Water utility	Workshop	Responsible for groundwater protection in the forests of Fuhrberg field at Hannover Water Utility (Quest. B)
PR	Primary	Water utility	unstructured	Political scientist, editor of the annual sustainability report of Enercity (e.g. Enercity 2011a)
Landscape planner	Primary	Landscape Planning	Semi-structured	Conducted Participatory planning in Fuhrberg. Professor in Landscape planning and nature conservation at LUH (Quest. C)

* Scientist 1 was interviewed twice

3.5.2 Embedding context

3.5.2.1 Implementation of the WFD in the Fuhrberg watershed

The Fuhrberg watershed, with 331 square kilometers, is the largest water protection area in Lower Saxony. While an interesting analysis of the evolution of metropolitan governance in Hannover can be found in Heinelt and Zimmermann (2011), here the focus was put on the implementation of the Water Framework Directive for its extreme relevance for the case study research. As shown in Figure 3.7, legal basis for protecting water resources in Lower Saxony is provided by the environmental objectives of the Water Framework Directive, while the actual implementation, as shown in Table 3.6, is delegated to lower levels up to the sub-basins level (Kastens and Newig 2007, 2008).

Water Framework Directive (WFD) - Transboundary River Basin Management
The main environmental objectives of the WFD Article 4II.1. Legal basis and environmental objectives WFD

Groundwater	Surface waters
Good quantitative and chemical status by 2015 Prevent or limit input of pollutants Reversal of significant pollution trends	Good ecological and chemical status by 2015 Reduce pollution from priority substances Prohibition of deterioration

↓

Target for nitrate in groundwater and surface water: 50 mg/l (annual average)

Figure 3.7: Environmental objectives of the Water Framework Directive providing legal basis for protecting water resources in Lower Saxony (source: Enercity)

More specifically, Table 3.6 illustrates how the protection of water resources, including Water Framework Directive and Groundwater Directive, is actually implemented at different scales, from EU to the sub-watershed level. As argued by Kastens and Newig, actual protection of water resources depended on an interplay of a number of “contextual” and “contingent” factors as well as on the relative influence (i.e. power) of different social actors (Kastens and Newig 2007, 2008). Contextual factors are relatively stable (e.g., cultural orientation, demographic composition, socio-economic conditions), while contingent factor are relatively changeable (e.g., public attention, financial means, current problem pressure). Table **3.7** summarizes the main contextual and contingent factors for the case of the Fuhrberg watershed, mainly based on the extensive analysis by Kastens and Newig, (2007, and 2008), confirmed by the key informants.

Table 3.6: Provisions of nitrate reduction at the different implementation scales of the Water Framework Directive (based on Kastens and Newig, 2007)

Decision-making scale	Institution	Discretionary competence/decisions made
European Union	WFD§ (2000)	Physico-chemical elements derived from "good ecological status" for surface water bodies (Annex V, Tables 1.2.1–1.2.5 WFD)
	GWD‡ (2006)	Area-wide limit of 50mg/l for nitrate (Annex I No. 1 GWD)
	CIS†	Ecological classification rules, but no concrete target values for physico-chemical elements. Operationalization of parameters is shifted to member states (CIS Guidance Document Ns. 13, 10, 4, 7)
	DWD± (1998)	Limiting values for drinking water extraction areas
	ND≠ (1991)	50mg/l orientation value to implement action plans for nitrate reduction
Fed. Rep. Germany	Fed. govt. LAWA¥	Merely legal implementation (done in 2004) Recommendation of target values
Lower Saxony (Länder)	State govt. (MELS#)	Final competence for implementation (operationalization of goals, measures, structuring of public participation process); but delegation of competencies to sub-basin scale
Fuhrberg watershed	Area co-operations* (since 2005)	Determination of management targets for waters, particularly application of exceptions; draft elaboration of programmes of measures

§ Water Framework Directive
‡ Groundwater Directive
† Common Implementation Strategies
± Drinking Water Directive
≠ Nitrate Directive - integral part of WFD
¥ "Länderarbeitsgemeinschaft Wasser" German Guidance Document for the Implementation of the WFD of the "Länderarbeitsgemeinschaft Wasser", updated version 30.04.2003.
Lower Saxony's Ministry of the Environment
* "Area co-operation" introduced following previous experience of "Drinking area co-operation" (1992-2005).

Table 3.7: Contextual and contingent factors affecting implementation of the Water Framework Directive in Lower Saxony (based on Kastens & Newig 2007, 2008)

Contextual factors	• Regional identity influenced by a strong social and economic role of agriculture • Most actors have a long tradition of collaboration with other actors regarding issues of water protection from agricultural pollution. This promising experience can be built upon. • Key actors show a rather protective stance regarding regional agriculture. They deprecated any measures to improve the nitrate situation that potentially harms the farmers' community or urges them to change their practices without financial compensation. • The only actors who are scarcely "integrated" but still bear a great potential for pushing ecological issues within the WFD implementation are the environmental NGOs.
Contingent factors	• Influence of Environmental NGOs on Public Participation • Biogas Plants for Manure Processing • New financial options (EU funding) • Ad hoc collaboration with Landscape planners from the Institute of Environmental Planning, Leibniz University of Hannover

3.5.2.2 Local newspaper articles on Fuhrberg watershed

The local newspaper “Hannoversche Allgemeine Zeitung” (HAZ) published 39 articles dealing with water issues in the Fuhrberg watershed. They appeared during1956-1994. They were classified into eight emergent topics, based on content analysis (see Figure 3.8). Most of the articles appeared during the 1980s and dealt with quantity-related issues, including the negotiation for water rights (i.e. volume of water HWU to abstract), and the negative impacts of excessive water abstraction on forest ecosystems. The first article concerning water quality problems dated back to 1982: in a long interview, the then head of HWU’s water laboratories blamed intensive fertilization from agriculture as the main cause of groundwater quality deterioration. The remaining newspaper articles dealt with less controversial issue, such as successes of groundwater-friendly practices.

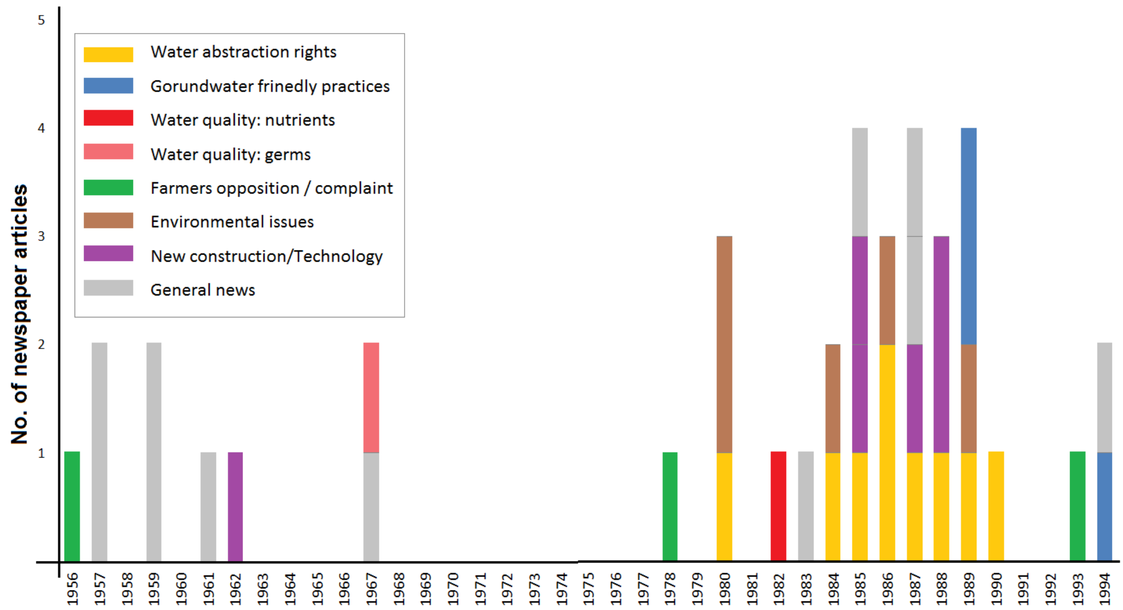


Figure 3.8: Classification of newspaper articles about Fuhrberg watershed.

Taken singularly, newspaper clippings can be biased towards the interests of specific actors, such as the farmers or HWU. Both are relatively powerful lobbies in the region and have high stakes in the Fuhrberg watershed. Nevertheless, covering a long time period allowed analyzing interactions between stakeholders over time (e.g. HWU and farmers) as well as trends in concerns and levels of social awareness (i.e. newspaper readers). In addition, newspaper articles provided detailed information about crucial events, such as the visit of the then minister of environment to the Fuhrberg watershed. This was useful for gaining deeper levels of inquiry during interviews with informants; thus reaching the desired fine-grain empirical resolution.

3.5.3 Empirical evidence of boundary work in Fuhrberg watershed management

Table 3.8 shows the five representative boundaries, which were investigated empirically to illustrate the role of boundary work in adaptive watershed management for ecosystem services in the Fuhrberg; each boundary is color coded as in Figure 3.6. Based on the framework by Clark et al. (2011), the boundaries were characterized in terms of the context (i.e. use and source of knowledge) and the most appropriate boundary work strategy.

Table 3.8: The characterization of the five most significant boundaries in the Fuhrberg watershed management case study, according to Clark et al. (2011).

Boundary	Context	Strategy	Code	
Boundary between problem-specific and generalizable research	Sn-Uo	Integrative R&D	A.1	
Boundary between new discoveries and established knowledge	S1-Uo	Demarcation	A.2	
Boundary between scientists and utility management	S1-U1	Expert advice	B.1	
Boundary between extension service and farmers	S1-U1	Expert advice	B.2	
Boundary between landscape planning and watershed management	S1-Um	Assessment	C.1	

§ Refers to code shown in Figure 3.1 and Figure 3.6

In the following sections, an account of the main barriers to knowledge transfer and empirical evidence of boundary work is provided. For greater clarity, the sections are structured according to the main barriers and attributes of boundary work (i.e. Participation, Accountability, and Boundary object) including some useful temporal references.

3.5.3.1 Boundary between problem/context-specific and generalizable research - A.1

Boundary A.1 refers to the late 1970s, when general agreements had to be reached between the then head of HWU’s water laboratory (a chemist) and a senior soil scientist from FRISSH. The two met fortuitously during a conference and learned of some common scientific questions they had concerning groundwater in the Fuhrberg watershed; this was the basis for their decision to join forces, secure funding, and conduct scientific research.

Barriers: In A.1, the main challenge was to integrate HWU’s urgency to identify concrete “solutions” (e.g., HWU was considering building a new treatment plant) with the need to perform state-of-the-art scientific research. In fact, HWU and FRISSH had different views about the successfulness of a research project, reflecting their respective missions and interests. In general, our informants (from both HWU’s and FRISSH’s side) consider the effort needed to foster long-term collaborations a barrier to knowledge transfer, especially in the absence of overlapping and specific objectives.

Participation: HWU and FRISS have jointly taken part in various activities, including writing a research proposal to apply for funding (late 1970s), setting-up experimental plots, sharing long-term field measures and data, and coordinating research activities and results (early to mid-1980s). Generally, HWU maintains good relations with numerous research institutions and universities. Among other things, exchanging information, data and interests, hosting internships, and supervising bachelor and master theses help maintain these relations.

Accountability: A key role was played by the commitment and reputation of the then head of HWU's water laboratories, who was both a manager and acknowledged scientist with more than 10 peer-reviewed scientific publications. Moreover, FRISSH's formal commitment to carry out applied research and disseminate findings, ultimately to support policy and decision-making, was also crucial. In addition, accountability was assured by HWU's strong "public thinking" (HWU had only recently changed from a public to a joint-stock company owned by the city), and informal collegiality between the local scientific community and HWU's management, which included many Ph.D.'s and M.Sc.'s.

Boundary objects: The most significant boundary objects were perhaps the common scientific questions concerning groundwater quality in the Fuhrberg watershed, which drove the whole process of knowledge generation. Other examples of boundary objects include the funding of the research by the "Deutsche Forschungsgemeinschaft" – DFG, i.e. German Research Foundation (early 1980s); a better scientific understanding of determinants of groundwater quality and quantity (early to mid-1980s); seven peer-reviewed papers co-authored by HWU and FRISSH (1985-1990); co-supervision of diploma and master theses and internships in HWU (ongoing).

Classification: Based on empirical evidence, A.1 was classified as Sn-Uo, i.e. knowledge originating from multiple communities of expertise (Sn) for enlightenment (Uo). Accordingly, the most appropriate boundary work strategy and effectiveness criteria are, respectively, Integrative Research & Development and Credibility (Clark et al. 2011). Boundary A.1 lied at the interface between two different interests, rather than two fields of expertise. Management of A.1 primarily aimed at gaining a better scientific understanding of the determinants of groundwater resources in the Fuhrberg watershed. However, to a certain extent, it also had to ensure the new scientific findings were as readily available as possible for use by HWU, to identify and assess feasible and cost-effective solutions. In fact, although A.1 dealt primarily with biophysical aspects related to groundwater quality, the (economic) implications from HWU's perspective also played a significant role; therefore I assume the involvement of multiple communities of expertise (Sn). The main use of knowledge, on the other hand, was Enlightenment (Uo), of which HWU would be later on the main and direct beneficiary. In general and other than the research project carried out during the 1980s, empirical evidence confirms HWU's high interest in scientific research, which it pursues in various forms, including active participation, provision of data and experimental plots, incentives for employees, internships, and thesis supervision. In terms of effectiveness criteria, although scientific Credibility was the main one, empirical evidence also highlights the role of Saliency. Here, saliency refers to level of readiness of the research findings with respect to HWU's specific needs. Therefore, it was found useful to distinguish between short and long-term management of boundary A.1. In the first case, both the problem to be investigated and its potential contribution to science (and more or less directly to HWU) were relatively well defined. Consequently, boundary work also had to be defined to a similar level of detail, for instance, by selecting methods and data to be utilized to ensure both local relevance and generalizability. For long-term and less specific engagements, on the other hand, the role of informal collegiality, sharing of interest, organizing internships, institutional and physical closeness was found to be more prevalent.

3.5.3.2 Boundary between new discoveries and established knowledge - A.2

Boundary A.2 refers to specific and operative arrangements made while conducting intensive research on groundwater quality in the Fuhrberg watershed, from the early to mid-1980s. As such, A.2 built on prior and more general agreements made for boundary A.1.

Barriers: The main challenge dealt with how to accept a particular new claim into the body of accepted, reliable knowledge. To start with, members of the joint research group had different explanatory assumptions about the causes of water quality deterioration in the Fuhrberg watershed, based on their own expertise. For instance, the then head of HWU's water lab assumed intensive fertilization was the main cause, quite in disagreement with the soil scientists from FRISSH.

Participation – Accountability - Boundary objects: Empirical evidence showed how overcoming these disciplinary differences to address open scientific questions, benefited from boundary work that ensured participation, (e.g. formulating hypothesis, hence, coordinating research activities), accountability (peer-review, statistical data evaluation, models etc.); and boundary objects (e.g. 26 peer-reviewed scientific papers, of which seven are co-authored by HWU and FRISSH).

Classification: Boundary A.2 was classified as S1-Uo, i.e. knowledge originating from a single community of expertise for enlightenment. This is a typical example of research within the natural sciences (S1) that aims to contribute to the body of existing knowledge (Uo). In fact, the different explanatory assumptions of the groundwater issues in the Fuhrberg watershed (e.g. biochemistry and soil science perspectives) all relied on the same approaches and tools, including plot experiments, statistical data analysis, and modeling. Accordingly, the most appropriate boundary work strategy was Demarcation, while Credibility was the main effectiveness criteria.

3.5.3.3 Boundary between scientists and water utility - B.1

Good management of A.1 and A.2 was crucial for generating new scientific knowledge that was credible and, to a certain extent, readily available for use by HWU. Yet, additional effort was needed so that these new scientific findings (e.g. the role of biochemical processes and historical land use conversions) could actually be informative for HWU's planning and decision-making. Accordingly, from the late 1970s to the late 1980s, boundary B.1, at the interface between the scientists and HWU, had to be managed. In B.1, boundary work was primarily aimed at persuading HWU's management to take part in a research project, follow and support its developments, and ultimately integrate its findings into HWU's planning and decision-making.

Barriers: Several barriers to knowledge transfer were identified, including an initial lack of awareness and response from HWU's management (late 1970s), difficulties in including scientific research among HWU's priorities (early 1980s), and the need to address groundwater problems through watershed measures, by involving farmers (late 1980). These barriers were compounded by an initial lack of awareness and collaboration from local authorities (late 1980s). Generally, a critical barrier was the communication of uncertainties and other complex concepts to non-scientists.

Participation: All the phases of the scientific research project saw an active involvement by both HWU and FRISSH. This included the setting of priorities, conducting experiments, analyzing data, and evaluating activities. Most importantly, the research project specifically addressed HWU's groundwater quality problems, employing long-term data from its waterworks, and utilizing experimental plots in the Fuhrberg watershed.

Accountability: As in A.1, the commitment and reputation of the then head of HWU's water laboratories played a pivotal role also in B.1. By way of example, mentioned here is a newspaper interview in which he openly accused the intensive fertilization by farmers as being the main cause of the deterioration of groundwater quality in the Fuhrberg watershed (HAZ article 04/09/1982). This was a good example of his attempts to raise public awareness and, simultaneously, advance groundwater quality issues in the agenda of HWU and other stakeholders. Other factors that contributed to an increase in accountability included HWU's previous involvements in research projects (e.g. development of new treatment technology for groundwater with high organic content, as is the case of the Fuhrberg watershed) and a good educational background of HWU's employees, which included Ph.D.'s and M.Sc.'s.

Boundary objects: Arguably, the most important boundary object was the long-term groundwater quality data, based on measurements from HWU's waterworks (Figure 3.5). During the late 1970s, this data showed a stepwise increase of groundwater sulfate concentrations of up to 200 mg/l, and the possibility of exceeding the water quality standard of 250 mg/l within a few years (see blue line in Figure 3.5). The funding of the research by the German Research Foundation was also another example of boundary object. In general, but to different extents, all the decisions taken by HWU that were based on the new scientific findings could be considered as boundary objects. This includes the decision to launch advisory extension services to promote groundwater-friendly agricultural practices, through voluntary agreements with farmers (late 1980s). Quite interestingly, monetary compensation for farmers was initially from HWU (1989-1993), and later from the State of Lower Saxony, following the introduction of a water fee (since 1992). Another example is HWU's decision to buy more land in the watershed (late 1980s), which according to interviewees was also partly due to the popularity of hunting among HWU's managers. Moreover, in the early 1990s HWU integrated its expertise by hiring staff with good scientific backgrounds (e.g. a Ph.D. and two M.Sc.'s.) and with practical experience related to water and soil, and agriculture. Finally, a strategic decision dealt with a gradual conversion of coniferous forests to deciduous ones, due to their lower nutrient leaching and higher groundwater recharge (late 1990s). Today, HWU makes substantial investments in forest management, following a number of key research findings that showed that nitrogen pollution of groundwater recharge from forests is 4 mg/l, compared to 88.9 mg/l from fields and grasslands.

Classification: Based on the empirical evidence, boundary B.1 was classified as S1-U1, i.e. knowledge from a single community of expertise (S1) in support of a decision by HWU (U1). Today, in its decision-making, HWU perceives the abovementioned knowledge as originating from a single community of experts, consisting mainly of natural scientists (some of which are HWU's employees). According to Clark et al. (2011), the most appropriate boundary work strategy is Expert advice, while Credibility and Saliency (for HWU) are criteria that should be jointly considered.

3.5.3.4 Boundary between extension service and farmers - B.2

Boundary B.2 lays at the interface between farmers and HWU and it was mainly concerned with promoting science-informed watershed measures to protect groundwater resources.

Boundary B.2, which chronologically follows B.1, went thorough different phases over time. From strained relations over water quantity issues (from 1959-late 1980s), to a "one-direction extension" model promoted by HWU (from late 1980s until early 1990s), followed by a formal introduction by the State of Lower Saxony of the so-called "drinking water co-operations" (early 1990), and "area co-operations" (since 2005). The "drinking water co-operations" consisted of roundtables involving mainly farmers, water suppliers, and local authorities. Their main goal was to promote groundwater protection in extraction areas, with funding from a newly introduced water abstraction fee in Lower Saxony (MU Niedersachsen, 2002, cited in Kastens and Newig, 2007). On the other hand, "area co-operations" consisted of working groups conceived as long-term institutions that actively contribute to the implementation, at sub-basin level, of the WFD (MU Niedersachsen, 2005, p. 2 cited by Kastens and Newig, 2007). Theoretically, "area co-operations" were expected to integrate all societal perspectives, including those of industry and environmental groups (Kastens and Newig, 2007). Therefore, in the context of boundary B.2 "area co-operations" were not considered, given they implied an active involvement of several actors beside water utilities and farmers, which was beyond the scope of investigation. Instead, the focus was on the "drinking water co-operations" (i.e. early 1990 to early 2000s), which primarily involved farmers from the Fuhrberg watershed and HWU's extension service.

Barriers: A main barrier was the long-term tense relations between farmers and HWU, mainly concerning water quantity issues (1956-1980s). According to the then head of the extension service (Water Manager 1), HWU and farmers lacked any meaningful communication, and consequently "couldn't see each other's motivations" (until late 1980s). The prevailing mistrust made the communication of complexities and uncertainties to non-scientists very challenging (until early 1990s). Prior to the early 1990s, another barrier was the simplistic framing of problems (e.g. as being caused by over-fertilization) and of the following proposed solutions (e.g. buying up to 80% of land in the watershed, with money from HWU and the State of Lower Saxony, to promote groundwater protection). Later on, a barrier was the prevailing one-directional extension model, in which priorities were defined in terms of HWU's groundwater-quality problems with little consideration for farmers' needs and interests (until early 1990s and before the introduction of the "drinking water co-operations"). Tense relations between HWU and other social actors representing farmers, such as the Chamber of Agriculture and Agricultural Associations, was also initially a barrier. These actors felt somehow "overruled" by HWU's watershed initiatives (Water Manager 1). In fact, our informants acknowledged the lack of a third party that could have created a neutral meeting ground for HWU, farmers, and other stakeholders as a barrier to knowledge transfer (until early 1990s). Finally, with hindsight, our informants considered excessively optimistic expectations from groundwater protection measures also a barrier.

A set of boundary work activities, put in place by different actors at different times, had been crucial for overcoming these barriers.

Participation: The most significant was perhaps the engagement of farmers in the implementation of groundwater protection measures, through voluntary agreements and monetary compensation. The latter had benefited from previous formal agreements on water abstraction rights (dealing with water quantity), which was reached after more than ten years of discussions (e.g. HAZ article 15/05/1990). However, key informants agree that participation was initially mainly driven by HWU's interest in reducing nitrate input and preserve long-term groundwater quality. While farmers' participation was mainly due to compensation money, legal obligations, peer-control, and a sense of belonging. Financially, voluntary agreements were initially covered by HWU (i.e. 1989-1992), hence by the State of Lower Saxony, following the introduction of a water fee in 1992. An improvement of the interaction with farmers was achieved when HWU hired young staff with good scientific backgrounds and with practical experience related to water, soil, and agriculture (early 1990s). Finally, participation was boosted following the introduction of the "drinking water co-operations" in Lower Saxony in 1992. Such roundtables involved water suppliers, farmers, the Chamber of Agriculture, and agricultural associations; and they were facilitated by the regional and local administrations (e.g. the "Bezirksregierung"). In the Fuhrberg watershed, for instance, discussions were held in regular meetings facilitated by the local authorities (Until mid-2000). Operatively, elected representatives of the farmers were involved in evaluating feasibility and costs of groundwater protection measures, proposed by experts from HWU or the Chamber of Agriculture (Water Manager 1).

Accountability: In B.2, accountability was mainly ensured by the "Drinking area co-operations" (from 1992 until 2005) and "Area co-operation" (since 2005). Other accountability measures include HWU's strong "public thinking" and the individual commitment of its extension staff to combine scientific interests with practical applications (e.g. *"...personally it was a chance to combine a little bit of research and scientific things with practical application. In fact, the head of the department where I started to work (in early 1990s) also had a Ph.D., and I knew that his group was using groundwater modeling, and that was a very interesting thing to work on*"). Similarly, sustained collegial relationships between participants of the "drinking water co-operations" were also crucial, (e.g. "*we knew many of them (...) because we were classmates at the university*").

Boundary objects: The most significant boundary objects are perhaps the voluntary agreements coupled with compensation money. To give an idea of this, currently around 70% of the agricultural area in the Fuhrberg watershed is covered by voluntary agreements, with

18 million Euros spent on water protection measures and advisory services in 2013 alone. Another example of a boundary object is the improvement of groundwater quality (e.g. sulfate concentration dropped from 200 to 150 mg/l), in part, also due to adoption of groundwater-friendly agricultural practices.

Classification: Boundary B.2 was classified as S1-U1, i.e. use of knowledge to support decisions taken by the farmers that are bound by voluntary agreements coupled with monetary compensations. The decisions were those related to implementation of groundwater protection measures, based on scientific knowledge originating from a single community of experts (i.e. water and soil experts from HWU or Chamber of Agriculture). According to Clark et al (2011), the most appropriate strategy was Expert advice, while effectiveness criteria included both credibility and saliency for the decision-makers, consisting of the "Farmers' community".

3.5.3.5 Boundary between landscape planning and watershed management C.1

Boundary C.1 refers to a landscape planning process, described in detail in von Haaren and Bathke (2008), which was here further investigated for evidence of boundary work. To start with, the landscape planning process aimed at integrating water protection and nature conservation in the Fuhrberg watershed, using landscape planning as the main instrument. In Germany, landscape planning is a well-established, comprehensive planning instrument (i.e. covers all levels of spatial and zoning planning), which is used for prevention-oriented nature conservation (von Haaren et al. 2008). Landscape planning includes the assessment of potential and actual ecosystem services and goods provided by an area, evaluation of impacts, as well as the definition of mitigation and compensation measures (von Haaren et al. 2008). An international comparative perspective of landscape planning can be found in von Haaren and Albert (2011).

In the Fuhrberg watershed, the planning process begun when HWU contacted landscape planners from the IUP at the Leibniz University of Hanover. The landscape planners accepted once they were assured by HWU that water protection, biodiversity, and nature conservation objectives would be included on an equal basis. The lead landscape planner was interviewed as a key informant (see Landscape planner in Table 3.5). Interestingly, landscape planning in the Fuhrberg watershed had been highly participatory, engaging different relevant stakeholders in various activities, including data collection, testing of innovative approaches, and funding (von Haaren and Bathke 2008). At the same time, HWU had also hired a private consultant, to gather all scientific findings dealing with water quality in Fuhrberg watershed and make them more accessible to laypeople.

Barriers: The difficulty in "translating" complex scientific knowledge and concepts; for instance, the biophysical models of groundwater quality in the Fuhrberg watershed that were available in the early 2000 were very complex, not spatially explicit, and generally far from being suitable for management and communication purposes. In fact, at the beginning of the planning process, framers still did not "believe" that their agricultural practices and land use changes could affect raw water quality in HWU's waterworks, even after more than 10 years of cooperation (Landscape planner). Moreover, farmers perceived HWU's interests as being too distant from their own; an example being the fact that at some point they felt pressured by HWU to introduce organic farming, despite its unpopularity amongst them (until mid-2000s). Another significant barrier was HWU's short-term investment return thinking (i.e. 5-10 years), which made the potential tradeoffs with long-term goals of biodiversity and nature conservation unfeasible (until early 2000s). Generally, the most important barrier was perhaps a lack of integration of the different priorities in the Fuhrberg watershed, including those of water protection, nature and biodiversity conservation, and agricultural production. For instance, until the early 2000s, water protection measures consisted of general bans on agricultural practices. These were based on a subdivision of the watershed into three concentric protection zones: Zone I, II, and II. Zone I was the closest to the waterworks, and thus had the most restrictive bans (see Figure 3.4). Moreover, there was limited understanding of how these neither area-specific nor spatially explicit water protection measures interacted with other nature protection initiatives. In fact, there were important synergies and tradeoffs; as the lead landscape planner put it, "*water and nature conservation can go together, but nature conservation is always more expensive and [...] most of the measures required for nature conservation are not so area consuming, and the water measures are more on the fields*".

Participation: In managing C.1, building upon previous efforts and interactions (e.g. "drinking water co-operations" in B.1), had been crucial for overcoming the abovementioned barriers. A joint setting of common objectives and agenda had been fundamental for initiating and fostering participation. This included the agreement to assign equal weight to water protection and nature conservation. Moreover, it included the hiring of a consultant to rearrange all available scientific evidences and make them "accessible" to non-experts (e.g. putting emphasis on interactive visualization). Another interesting example was a broadening of the initial objectives of water protection, and nature conservation, also to include explicit agricultural objectives. This decision was taken halfway through the planning process, when the first priority maps (i.e. dealing with water and nature protection) were presented to stakeholders. According to the lead landscape planner, in the farmers' perception, such priority maps gave more "power" and visibility to water, and nature conservation; therefore the farmers requested the preparation of agricultural priority area maps, agreeing to provide all needed support. The agricultural priority area maps, which exclusively illustrated agricultural production targets, combined input from farmers (e.g. bottom-up data collection and criteria assessment) and landscape planners (e.g. biophysical data and analysis of relevant policies). The landscape planners covered the costs of the research, mainly because the case study offered interesting, and potentially generalizable insights for policy-making (see von Haaren and Bathke, 2008). However, agricultural priority maps never made it to the public; in fact, having realized their implications in terms of future developments in the watershed, the farmers withdrew their consent for disclosure. Generally, participation benefited from substantial efforts made by landscape planners, who cultivated relationships with stakeholders, and brought them to a “neutral meeting ground”, to produce shared knowledge.

Accountability: The landscape planners had deployed many confidence-building measures to assure each stakeholder individually of the Saliency, Credibility, and Legitimacy of the planning process. This was achieved mainly through transparency in handling data and evidences, and by drawing on the reputation of the IUP as a neutral actor. Previous personal relationships and interactions of the landscape planners with the farmers had been crucial as well. Interestingly, in the case of the Fuhrberg watershed, the landscape planners had preferred commitment and reputation of a few key individuals (e.g. respected farmers instead of young nature conservation-friendly farmers) to any formal institutional mechanism.

Boundary objects: A good example are the interactive biophysical models prepared by the consultant, which summarized the most significant scientific evidences and made them readily available for management purposes as well as farmers involvement. Indeed, important boundary objects were also the maps of priority areas for water protection, and nature conservation. Such maps combined field measures with data from landscape planning, hence, identified different site-specific and spatially explicit water and nature conservation measures, as well as the related monetary compensation. Priority area maps went beyond the simple, existing general bans associated to the three water protection areas in the Fuhrberg watershed (i.e. Zone I, II, and III). Interestingly, the farmers had become supportive of the priority area maps, once they realized these maps bypass the general ban covering the whole watershed, in favor of site-specific restrictions. On the contrary, agricultural priority maps could not be considered boundary objects, since the farmers refused to share them, deeming them too sensitive.

Another important boundary object was the testing of innovative remuneration schemes for ecosystem services, related to water protection, and biodiversity conservation. Von Haaren and Bathke (2008) provided a detailed description of this innovative remuneration scheme, among other things, highlighting its relevance for the European Common Agricultural Policies. In the Fuhrberg case study, farmers were viewed as active producer of ecosystem services that could be “sold” in a market, and not as an affected contracting party who had to be compensated for financial losses (von Haaren and Bathke 2008). The public’s demand for ecosystem services, such as water and nature conservation, was the origin of the market; coherently, to run the “experiment”, landscape planners secured funding from the county of Hanover and the German environmental foundation (“Deutsche Bundesstiftung Umwelt” - DBU), first, and the State of Lower Saxony, later. The new approach had been assessed against conventional remuneration schemes, clearly demonstrating a significant “environmental success” as well as positive effects on the motivation of the farmers (von Haaren and Bathke 2008). Generally, the landscape planning process resulted in a highly participatory and transparent research that changed minds and identified key win/win options for both water protection and nature conservation. Yet, not all the outputs of the planning process were publicly shared, mainly due to the concerns of the “Farmers’ community”.

Classification: Arguably, boundary C.1 was classified as S1-Um, in which mainly knowledge from a single community of expertise (i.e. landscape planning) was used in support of negotiation among multiple stakeholders, including HWU, farmers, and local authorities. This classification may appear not to be in line with some empirical evidences, which show the use of multiple sources of knowledge (e.g. biophysical models by the consultant, farmers’ knowledge and data). Nevertheless, the analysis of empirical evidences suggested that the methodologies and data used by the landscape planners were the backbone of the whole planning process (i.e. management of boundary C.1). While the other sources of knowledge, which also fed the landscape planning process, were more instrumental in increasing the saliency and legitimacy of the boundary work activities. Therefore, the classification of the boundary C.1 as nearer to S1-Um rather than Sn-Um, and “Assessment” as the most appropriate strategy (Clark et al. 2011).

3.6 Discussions and conclusions

This chapter empirically investigated the extent to which the concept of boundary work can facilitate transfer of knowledge into action in an adaptive watershed management for ecosystem services. Following a review of the theoretical background of boundary work, it introduced the case of the Fuhrberg watershed management as highly informative about boundary work in practice.

The main finding of this chapter was that the framework of boundary work by Clark et al. (2011) proved very useful for understanding facilitation of knowledge transfer in adaptive watershed management for ecosystem services. Generally, the framework provided guidance on how to address successfully the "linkage of a set of diverse stakeholders and knowledge systems, across management levels, and across sector" (Kowalski and Jenkins, 2015). A key aspect of the generalized framework was the requirement of a clear definition of the context in terms of "why knowledge is being used", and "how users perceive the source", thus defining nine possible combinations. The context is the main factor for identifying the criteria to consider, and the most appropriate boundary work strategy to achieve them. Moreover, in the chapter it was acknowledged that boundary work is not a single time achievement, rather a dynamic process that has to address a diverse set of "tensions" (Parker and Corona, 2012). Boundary work should be seen as part of a dynamic a process that takes place within an embedding socio-ecological context, as such is highly affected by the relative influence of social actors, which in turn is crucial in shaping interactions between knowledge users and producers. Therefore, a detailed understanding of the contextual and contingent factors and relative influence of social actors is a prerequisite for any boundary work. Furthermore, in the chapter it was argued that the distinction between the nine combinations of knowledge use and source proposed in Clark et al 2011 (Figure 3.1), should not be drastic; rather there should be gradual transition from on context to its neighboring ones. Following are some of the findings that stand out for discussion.

3.6.1 Overcoming barriers of knowledge transfer

A large variety of barriers to knowledge transfer was identified, which is consistent with the findings in Clark et al. (2011). In particular, it was found that the more ambitious the use of knowledge (i.e. moving from enlightenment to support of decision and negotiation), the more challenging the barriers of the knowledge to action transfer. The analysis showed that convincing stakeholders of the saliency and legitimacy of knowledge could be much more difficult to achieve than ensuring credibility.

3.6.2 Use of knowledge for Enlightenment

In terms of boundary work, the use of knowledge for enlightenment is the least problematic context; in fact, the only concern is assuring credibility in the handling of knowledge. In the case study, two distinct boundaries were identified: a boundary between problem/context specific and generalizable knowledge (A.1) and a boundary between new discoveries and established understanding (A.2). The boundary work strategies put in place in A.1 and A.2 were, respectively, Integrative R&D and Demarcation (Clark et al. 2011). Chronologically, A1 had been managed first, mainly to assure the engagement of HWU; henceforth, A2 had benefited from such boundary work activities. In both A.1 and A.2, boundary work produced several boundary objects, suggesting that the interaction between knowledge users and producers had been very close to a theoretical potential of interaction (Clark et al. 2011). However, it was acknowledged that water managers could have a difficulty in justifying investment of scarce resources in boundary work, whose benefit is neither immediate nor granted, hoping in a trickle-down effect of science. Among others, a water utility's willingness to engage in scientific endeavors arguably depended on the extent to which it could potentially benefit from the findings (e.g. readily available new technology, corporate image), and availability of human and financial resources.

More generally, it could be assumed that the willingness to engage depended on the utility's institutional capacity (Kayaga et al. 2013), or dynamic capabilities (Lieberherr and Truffer 2015). As will be discussed in Chapter 5, Kayaga et al (2013) define institutional capacity as "the capacity of institutions to continuously generate a minimum level and quality of valued outputs and to prioritize learning for continuous improvement". Similarly, Lieberherr and Truffer (2015) regard "engaging in regular collaboration and exchange with experts in research institutes, universities or professional associations", as an integral constituent of the dynamic capabilities of "sensing", "seizing", and "reconfiguring" of a water utility (Lieberherr and Truffer 2015). The case of Fuhrberg watershed re-emphasized the importance of institutional capacity in enhancing the use of knowledge for enlightenment. By any standard, HWU has a very high institutional capacity, which among other things increased the possibility of it being involved in research projects with partners. Although similar cooperation initiatives between water utilities and land users have been successfully implemented in several other regions in Germany, Europe, and the world, the Hannover Water Utility case study is unique. What makes it unique is the long-term establishment of cooperation, the intense collaboration between practitioners and researchers, and the specific natural science complexities that made the study area an interesting site for research.

3.6.3 Use of knowledge for Decision Support

In the context of knowledge use for decision-support, the most important aspect was the extent to which decision-makers perceived the handling of knowledge as credible and salient, by adequately addressing their concerns. In the case of the Fuhrberg watershed, the stakeholders that most affected knowledge transfer are HWU (boundary B.1) and the "Farmers' community" (boundary B.2). The empirical investigation showed that in B.1 boundary work contributed to a full integration of scientific findings in HWU's planning and decision-making. Hence, it is possible to conclude that the theoretical potential of interaction between the HWU and the "Scientific community" has been achieved. Mainly, this success was attributed to HWU's high institutional capacity or dynamic capabilities. As will be discussed in Chapter 5, following Cowling et al (2008), we arguably assumed HWU could be considered a “learning organization” engaged in an adaptive watershed management for ecosystem services. On the other hand, interaction between HWU and the “Farmers’ community” across boundary B.2 had been far more challenging. This boundary had gone through different stages, characterized by different degrees of participation of “Farmers’ community” in decision-making processes. This included an initial stage, when the “Farmers’ community” was bound by decisions taken based on scientific knowledge, which they did not perceive as salient. Therefore, in B.2, although decisive, boundary work did not actually succeed in fully achieving the theoretical potential of interaction between knowledge users and producers. Rather, several other factors played key roles in facilitating knowledge transfer, including compensation money, new regulations, past collaborations, and peer control. In general, “contextual” (e.g. poor land productivity, a mixed farming structure) and “contingent” (e.g. increase in education level and generational change) factors as well as the relative influence of actors (Kastens and Newig 2008) were crucial for understanding knowledge to action transfer. Moreover, it is worth bearing in mind that boundary work is about managing tensions at the interface between stakeholders, whose interests and demands can sometimes be “incommensurable” (Parker and Corona, 2012).

3.6.4 Use of knowledge for Negotiation Support

Use of knowledge for negotiation support is the most challenging context for boundary work: in fact, it requires a simultaneous fulfillment of the criteria of credibility, saliency, and legitimacy. Moreover, striking the right trade-off among the criteria often requires capacity building to achieve a meaningful participation of all stakeholders (Cash et al. 2003, Kristjanson et al. 2009, and Clark et al. 2011). A good case in point of knowledge use for negotiation is the landscape planning process, which took place in the Fuhrberg watershed in the early 2000s. Its peculiarity was the degree of active involvement of the main stakeholders (von Haaren and Bathke, 2008). Among other things, the planning process included the translation of complex scientific knowledge and models into more comprehensible and interactive tools, the testing of innovative success-based schemes of payment for ecosystem services, as well as some attempts to integrate agricultural priorities, with water and nature protections ones (von Haaren and Bathke, 2008). Based on the empirical investigation, it could be argued that the planning process was in line with a new paradigm in water resource management that has an increasing awareness of uncertainty and change, and relies strongly on social learning (Pahl-Wostl et al. 2011, Albert et al. 2012). The empirical evidences of this research strongly support that the Fuhrberg watershed management covered, to different extents, all aspects of an adaptive watershed management as defined in Chapter 1.

Moreover, the case study offered interesting insights on the process of achieving such an adaptive watershed management, given a specific socio-ecological context. For instance, concerning the pivotal role of social learning, Pahl-Wostl et al. (2007) argued that it is not admissible that a particular "group of experts or stakeholders can learn on behalf of all other stakeholders". In the Fuhrberg watershed management, the "Farmers' community" was a good case in point. After seeing priority maps for water and nature protection goals, the farmers asked for agricultural priority maps and actively contributed to their development. However, they refused the disclosure of the maps once they "learned" about their sensitive nature and implications for future development (von Haaren and Bathke 2008). This was indeed an example of how social learning does not necessarily lead to more sustainable patterns of development. Another example was the one concerning the implementation of the Water Framework Directive in Lower Saxony (Kastens and Newig 2007, 2008) in which an apparently "lock-in situation" (Pahl-Wostl et al. 2007), due to contextual factors, may potentially accommodate social learning if contingent factors are considered (e.g. increased public awareness through NGOs engagement and new technology for treating biogas).

This chapter provided one of the first empirical assessments of boundary work in practice and presented many promising approaches for initiating and facilitating boundary work in the case of water utilities. The approaches for boundary work identified in the case study can be replicated in other water utilities – at least in cases with a similar governance context. Finally, the chapter identified that more comparative research is required to understand better the influence of contextual differences on appropriate methods and potential outcomes of boundary work, and to provide generalizable conclusions and guidelines for boundary work for water utilities and environmental resource planning and management.

Chapter 4

Designing and assessing watershed investments

4.1 Introduction

This chapter focuses on watershed investments (WI) to secure water for cities, seen as an effective tool for implementing adaptive watershed management. It explores how watershed investments can enhance the provision of drinking water, in synergy with other ecosystem services and social goals, to benefit urban populations in a cost-effective and sustainable way. Through a case study research, it builds and tests an operative approach for designing and assessing impact of watershed investments considering their unintended, and typically unattended, consequences both within and beyond the watershed. The proposed approach combines spatially explicit modeling of ecosystem services with some insights from the previous chapter on boundary work. Ultimately, its aim is to promote a meaningful interaction between stakeholders, within a frame of adaptive watershed management.

The here proposed approach consists in defining a set of objectives and related investment scenarios. Hence, in applying a relative-ranking approach, based on important biophysical factors that drive the ecosystem service, to design so-called “investment portfolios”, i.e. sets of activities in which to invest. This is followed by the generation of future land use scenarios that represent the implementation of the investment portfolios. Hence, the modeling of impacts on selected ecosystem services, and finally the assessment of the performance of different investment scenarios, with respect to baseline conditions. In building the approach, the original contribution consisted in the emphasis put on the fact that the abovementioned steps take place within a dynamic process of negotiation among stakeholders engaged in use and production of knowledge, as seen in Chapter 3. Therefore, the approach was structured in a way that reflects and facilitate such a process, highlighting boundary work that would be needed to facilitate knowledge into action transfer.

A case study empirically illustrates the potential application of the approach to a data-scarce context in Sub-Saharan Africa. The Toker watershed (TW) and its homonymous reservoir, which are the main water supply for Eritrea's only major city Asmara, are considered. The Toker watershed is affected by soil erosion- and water scarcity-related challenges, which hinder the city of Asmara from meeting its growing water needs and, at the same time, exacerbate poverty of rural communities. Thus, two illustrative objectives for investments in the Toker watershed were assumed to be: (a) urban water security and (b) rural poverty alleviation.

The application of the proposed approach to this case study addressed three key questions, formulated following Vogl et al (2015) as:

i. Which activities, when, and where in the watershed yield the greatest returns, under different investment scenarios?
ii. How do watershed activities affect the provision of selected ecosystem services?
iii. What is the performance of WI with respect to baseline conditions?

The remainder of the chapter is organized in six sections. First, the main characteristics and rationale behind of watershed investments are introduced (4.2). Second, a description of the Toker watershed case study in provided (4.3). Third, the proposed operative approach is described, specifying its rationale and application to the Toker watershed (4.4). Fourth, some illustrative results are presented in order to answer the abovementioned three key questions (4.5). Fifth, the results are critically discussed, highlighting opportunities for real-life application of the approach in the Toker watershed (4.6). Finally, analytical generalization is carried out to draw overall conclusion (4.6.2).

4.2 Watershed investments: a promising opportunity

Watershed investments, whose main purpose is to secure water for cities, represent a promising opportunity to effect large-scale transformative change that promotes human wellbeing while conserving ecosystems (McDonald and Shemie 2014, Guerry et al. 2015). According to an in-depth analysis of watersheds supplying five hundred cities worldwide, 25% of the cities would gain a positive return from watershed investments, with annual saving on water treatment costs exceeding US$ 890 million (McDonald and Shemie 2014). Watershed investments consist of governance and financial mechanisms that secure clean water for downstream users, mainly cities, and operate by engaging primarily upstream communities and nature conservation organizations (Higgins and Zimmerling 2013). They target a wide range of activities, from changes in land use and alteration of vegetative covers, to education, and community outreach; and so enhance selected ecosystem services such as erosion control and nutrient retention, while conserving nature and biodiversity. Watershed investments may also have explicit social objectives such as poverty alleviation, which comprises both poverty reduction, and prevention (Daw et al. 2011). Arguably, watershed investments can be considered an effective way of implementing adaptive watershed management. As such, designing and assessing watershed investments can be challenging because it has to deal with barriers and boundary work concerns that are similar to the ones analyzed in the previous chapter. Thus, the need of adequate approaches for supporting their implementation, by duly addressing the concerns of different stakeholders. This includes taking into account both contextual and contingent factors as well as the relative influence of stakeholders. In the context of this chapter, stakeholders were broadly defined as any actor that is affected by and/or can affect watershed investments, such as upstream communities, downstream users, water management agencies, conservationists, and funding bodies.

Consideration of the effects on ecosystem services is increasingly included in decision-making (de Groot et al. 2010, Maes et al. 2012, Abson et al. 2014, Haase et al. 2014) and impact assessment processes (Geneletti 2015, Mandle et al. 2015, Geneletti et al. 2016). In particular, spatially explicit modeling of ecosystem services allows to generate and explore future scenarios, and to understand the tradeoffs between different watershed investments objectives. Not only, but possibly optimizing co-benefits - for instance, by exploiting existing urban nexuses (GIZ and ICLEI 2014) and synergies between ecosystem services (Howe et al. 2014). Good examples that apply spatially explicit ecosystem services modeling for tradeoff analysis are found in (Polasky et al. 2008, Geneletti 2013, Lawler et al. 2014), to name a few. These studies demonstrate how a set of designed land use patterns can better meet competing objectives, such as nature conservation, agricultural production, and urban growth. Moreover, they highlight how existing land use patterns are often not “efficient”; thus, large margins exist for improving outcomes of a specific objective without negatively affecting the others (e.g. Polasky et al. 2008). Thus, starting from the concepts of ecosystem services and insights on boundary work in watershed management, by providing and operative approach, this chapter aims to support the implementation of watershed investments and, ultimately, adaptive watershed management.

4.3 Case study: The Toker watershed (Eritrea)

4.3.1 Socio-ecological challenges and watershed investment

Eritrea is a small country in Eastern Africa with a population less than six and half million. It is a prevalently rural country, almost 77 percent of the population, yet is currently undergoing rapid urbanization. During 1984-2010, its urban population had grown from 800.000 to

1.200.000, of which 37 percent took place in the capital, Asmara. With around 650 thousand inhabitants, Asmara accounts roughly for 10 percent of the total population in Eritrea. Since 1996, Eritrea got its independence in 1993; the country is divided in six administrative regions based on the main watersheds (See Figure 4.1). The case study area is located in the smallest and most densely inhabited region, the Central Region (i.e. “Zoba Maekel”), covering less than 1.2% of the total area yet hosting almost 17% of the total population. In this context, the focus was on the Toker watershed and its homonymous reservoir, built in the year 2000 for water supply to Asmara and its surrounding areas.

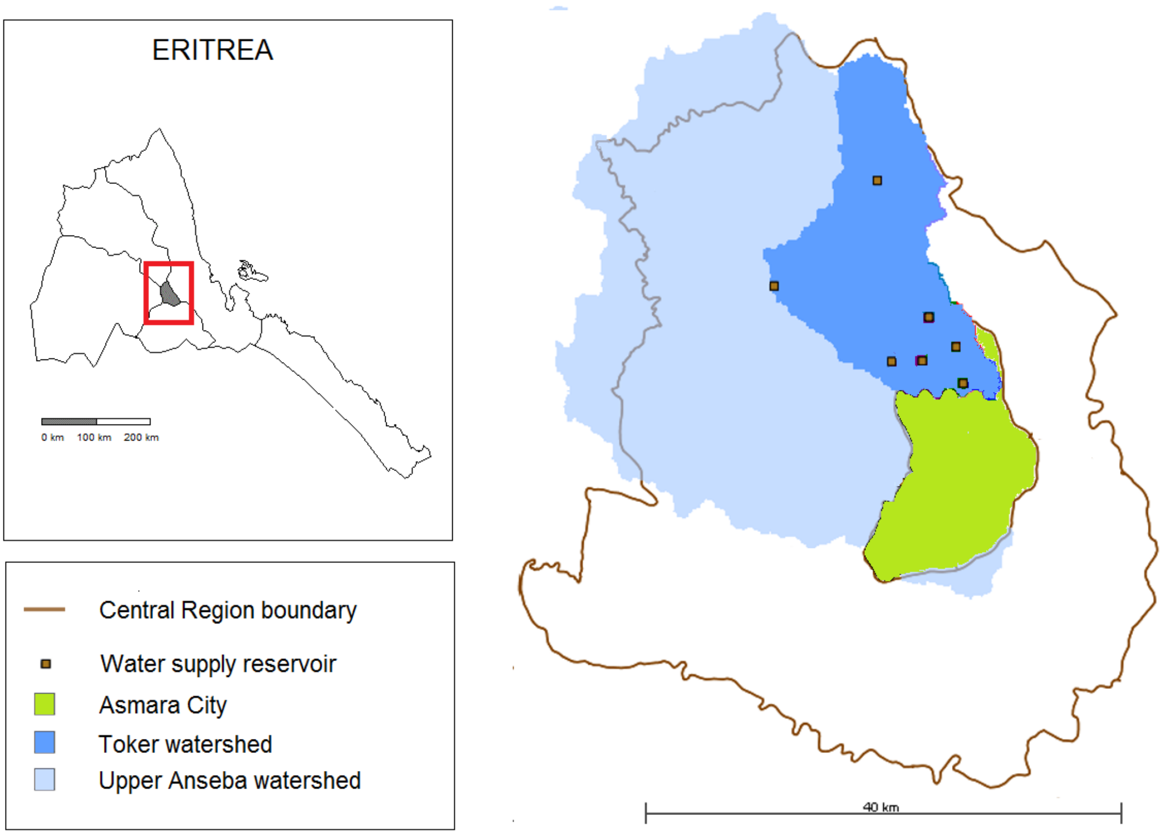


Figure 4.1: The Toker watershed, a sub-watershed of the Upper Anseba located in the Central Region, and the seven reservoirs that supply water to Asmara (right). The six administrative regions in Eritrea based on the main watersheds; the Central Region, the smallest and most densely inhabited in the country (left).

In the case study, soil erosion-, and water scarcity-related problems emerge among the most critical issues requiring urgent solutions. Soil erosion is caused by a long history of poor cultivation and overgrazing, unregulated wood and timber harvesting, lack of recycling of nutrients and poor management of organic matter, as well as rapid urbanization and demographic growth (Murtaza 1998, Tewolde and Cabral 2011). Water scarcity is mainly due persistent droughts associated with climate variability and change (Abraham et al. 2009, MoLWE 2012, IPCC 2014). Overtime, to face physical water scarcity, several reservoirs had been built to store surface water, during two wet seasons known as "kiremti" (June-September) and "asmera" (March-April). These reservoirs were the main sources of water for meeting urban and rural demands, including irrigation, livestock watering, domestic water supply, and other uses. Yet, soil erosion was rapidly decreasing their storage capacity, further compounding physical water scarcity in the region with economic water scarcity (Abraham et al. 2009).

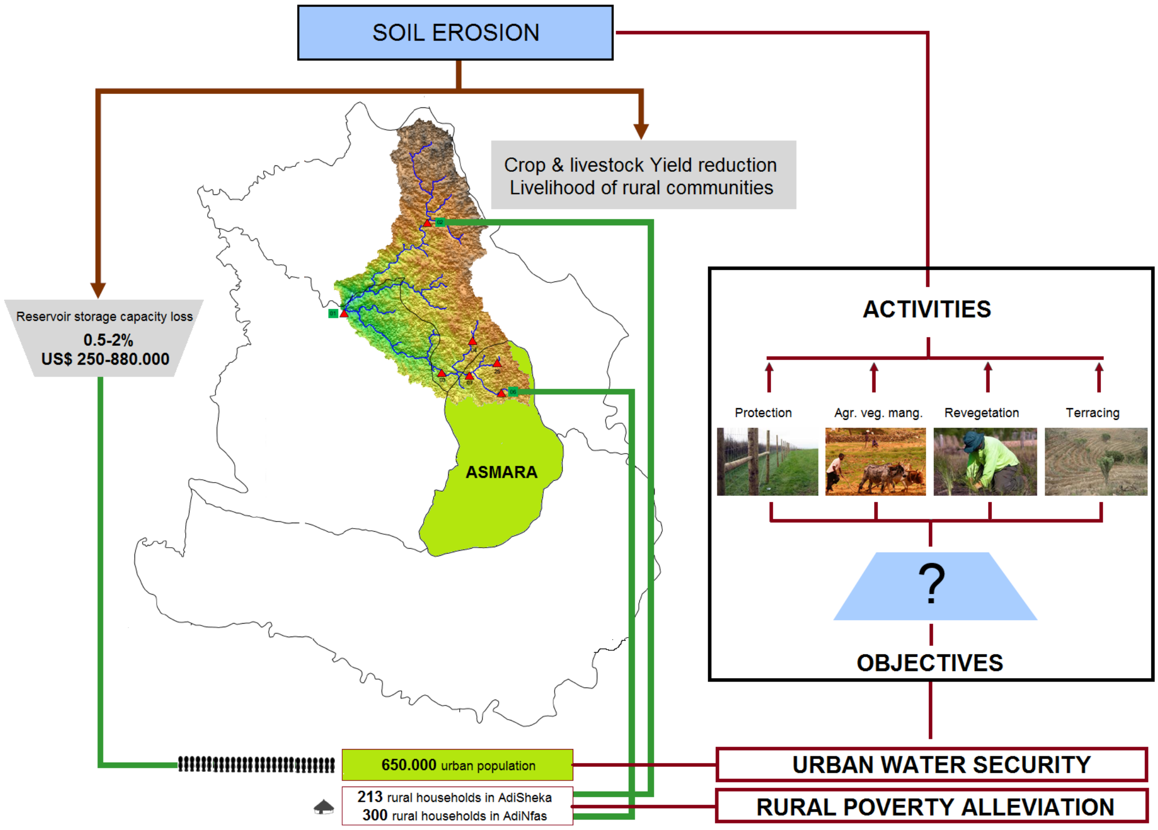


Figure 4.2: Framing of soil erosion-related challenges in the Toker watershed from an ecosystem services' perspective, highlight of (i) the spatial mismatch between areas of ecosystem services production and benefit, (ii) the different impacts on urban and rural beneficiaries, and (iii) the two illustrative watershed investment objectives in the case study application. Four types of activities covered by watershed investment, namely, protection, agricultural vegetation management, assisted revegetation and terracing.

As shown in Figure 4.2, the ecosystem services concept can be useful for effectively framing the abovementioned socio-ecological challenges, for instance, by highlighting how they diversely affect different groups of people (Daw et al. 2011). On the one hand, soil erosion causes a rapid loss of storage capacity of reservoirs supplying the city of Asmara. According to Abraham et al (2009), the estimated average sediment yields in the region is of 856 t/Km^2, which corresponds to an annual storage capacity loss between 0.5 and 2 percent (Abraham et al. 2009). On the other hand, soil erosion affects livelihood of rural communities by resulting in lower yields; in fact, the Food and Agriculture Organization (FAO) has estimated that a rate of soil erosion of 1500 t/Km^2 per year could reduce yields by 0.2-0.4% a year for crops and 0.05-0.1% for livestock (FAO 1994, as cited in (Habtetsion and Tsighe 2007). As for water scarcity, the total number of reservoirs in the Upper Anseba Watershed is 49, of which the 11 biggest ones (on which 7 in the Toker watershed) supply water to Asmara, and 38 smaller reservoirs serve rural communities for drinking and irrigation purposes (Abraham et al. 2009). The aggregated storage capacity of the 49 reservoirs is 32 million cubic meters, of which 24.8 million m^3 (77.4%) is reserved for Asmara. Nevertheless, Abraham et al (2009) have estimated that, due to siltation, only 55-89% of that storage capacity is still available. Therefore, soil erosion and water scarcity hinder the city of Asmara from meeting its growing water demands at the same time seriously jeopardize the main sources of income of the rural communities, whose livelihood depends primarily on rainfed agriculture. For this reason, the two illustrative objectives considered in this paper for investment in the Toker watershed are Urban Water Security and Rural Poverty alleviation (4.4.1.1).

4.3.2 Baseline conditions in the Toker watershed

Figure 4.3 shows the distribution of land use and land cover (LULC) in the Toker watershed, based on a simplified classification of LULC adopted by the RIOS approach (Vogl et al. 2015). More specifically, Table 4.1 shows the reclassification from Africover landuse classes to RIOS General landuse classes. In addition, Figure 4.3 shows the seven reservoirs in the Toker watershed and their respective sub-watersheds. As will be discussed in detail later on, they represent the entry points and spatial units for most of the analysis in the proposed approach. This includes the identification of stakeholders (e.g. rural beneficiaries) as well as definition of watersheds investment priority area for rural poverty alleviation (section 4.4.1.2).

Figure 4.3 and Table 4.1 are important assumptions mainly based on expert opinion, which would need to be confirmed by actual stakeholders. In fact, they represent the baseline conditions in the Toker watershed, which will be used to assess the performance of different scenarios of watershed investments. As such, with a proper involvement of the stakeholders, they have the potential to become a first boundary object of the process of design and assessment of watershed investments. This however, however, was beyond the scope of this study.

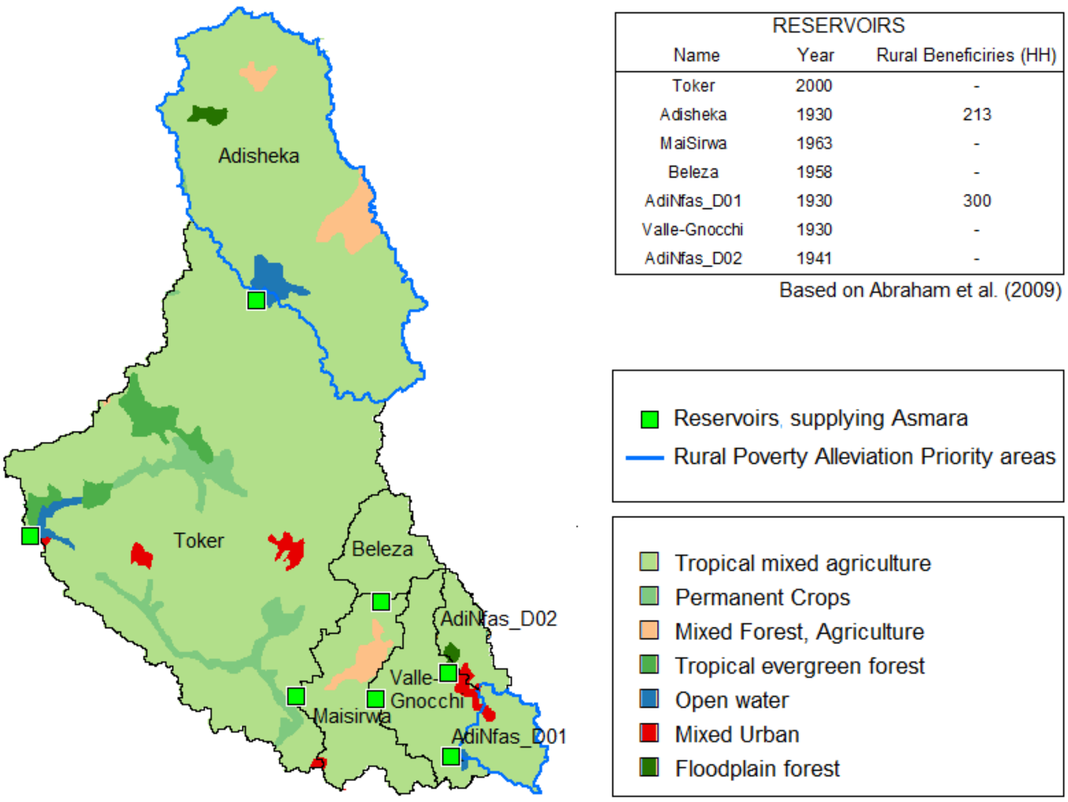


Figure 4.3: Land use in the Toker watershed based on a simplified RIOS classification. Location of the seven reservoirs and respective sub-watersheds that supply water to Asmara. Highlight of the two rural poverty alleviations priority areas, i.e. AdiSheka and AdiNfas_D01, based on the number of rural beneficiary households (HH).

Table 4.1: Reclassification from Africover to RIOS General landuse classes

AFRICOVER: Landcover Database for Eritrea –User defined classes	**RIOS General landuse classes**
Closed semi-evergreen trees with closed to open shrubs + Rainfed Herbaceous Crop agriculture	mixed forest, agriculture
Open shrubs with closed to open herbaceous and sparse trees + Rainfed Herbaceous Crop agriculture	mixed forest, agriculture
Forest plantation – Eucalyptus + Rainfed Herbaceous Crop, Small Fields, Clustered - Cereal"	mixed forest, agriculture
Urban area	mixed urban
Artificial lake	open water
Irrigated Non-Graminoid Crop	permanent crops
Sparse shrubs with sparse herbaceous	shrub/scrub
tropical mixed agriculture	tropical mixed agriculture
Bare soil + Rainfed Herbaceous Crop	tropical mixed agriculture
Rainfed Herbaceous Crop, Small Fields + Irrigated Non Graminoid Crop, Small Fields, Clustered - Vegetables	tropical mixed agriculture
Rainfed Herbaceous Crop, Small Fields – Cereal + Sparse trees with sparse herbaceous	tropical mixed agriculture
Rainfed Herbaceous Crop, Small Fields – Cereal + Forest Plantation, Clustered - Eucalyptus	tropical mixed agriculture
Irrigated Non-Graminoid Crop, Small Fields – Vegetables + Forest Plantation, Clustered - Eucalyptus	tropical mixed agriculture
Rainfed Herbaceous Crop, Small Fields – Cereal + Bare soil	tropical mixed agriculture
Forest plantation - Eucalyptus AND Artificial lake	floodplain forest
Artificial lake AND Forest Plantation, Clustered - Eucalyptus	floodplain forest
Forest plantation-Eucalyptus	tropical evergreen forest

4.4 Building and testing the operative approach

The proposed approach utilizes two software tools based on ecosystem service, created by the Natural Capital Project (RIOS and InVEST 3.2.0), at the same time builds on the concept of boundary work seen in chapter 3. RIOS stands for “Resource Investment Optimization System”; it allows targeting watershed investments, based on stakeholders’ ecosystem service objectives, their preferences about where activities may occur, and the amount of money that is available for implementing the activities (Vogl et al. 2015). Output from RIOS includes investment portfolios, where the most cost-effective locations for activities are provided. InVEST 3.2.0 is a suite of spatially explicit ecosystem service modeling tools that quantify service provision, based on the different investment scenarios (Sharp et al 2015).

The proposed approach is structured in a way that represents the process of negotiation between the stakeholders involved in watershed investments, mainly based on their different needs in terms of boundary work. To this end, as Figure 4.4, the approach was structured distinguishing between two interlinked components: (i) Strategic Component and (ii) Technical Component, with each component having three stages: i.e. Initial, Intermediate, and Final. The Strategic Component includes setting the agenda (4.4.1), defining investment scenarios (4.4.2), and assessing the performance of the resulting investments (4.4.3). The Technical Component consists of preparation and processing of biophysical data (4.4.4), tailoring of spatially explicit ecosystem service models (4.4.5), hence their application to generate investment portfolios and future land use scenarios, and to model impacts on selected ecosystem services (4.4.6). Although separately presented, the two components are tightly interlinked and feedback to each other, thus only jointly do they support the design and assessment of watershed investments. For example, preparation and processing of biophysical data is entirely dependent on the strategic agenda setting, while the assessment of the performance of different investment scenarios is based on an aggregation of the results from the technical component. In Figure 4.4, the arrows represent the interaction between stakeholders involved in knowledge use and production, thus the different needs in terms of boundary work. Put simply, the strategic component contributes in terms of saliency and legitimacy, while the technical component ensures credibility.

In the remainder of this section, each step of the approach is discussed. A general description of its rationale is provided, including useful references and specific application to the case of the Toker watershed. The Strategic Component of the proposed approach is presented first, followed by the Technical Component.

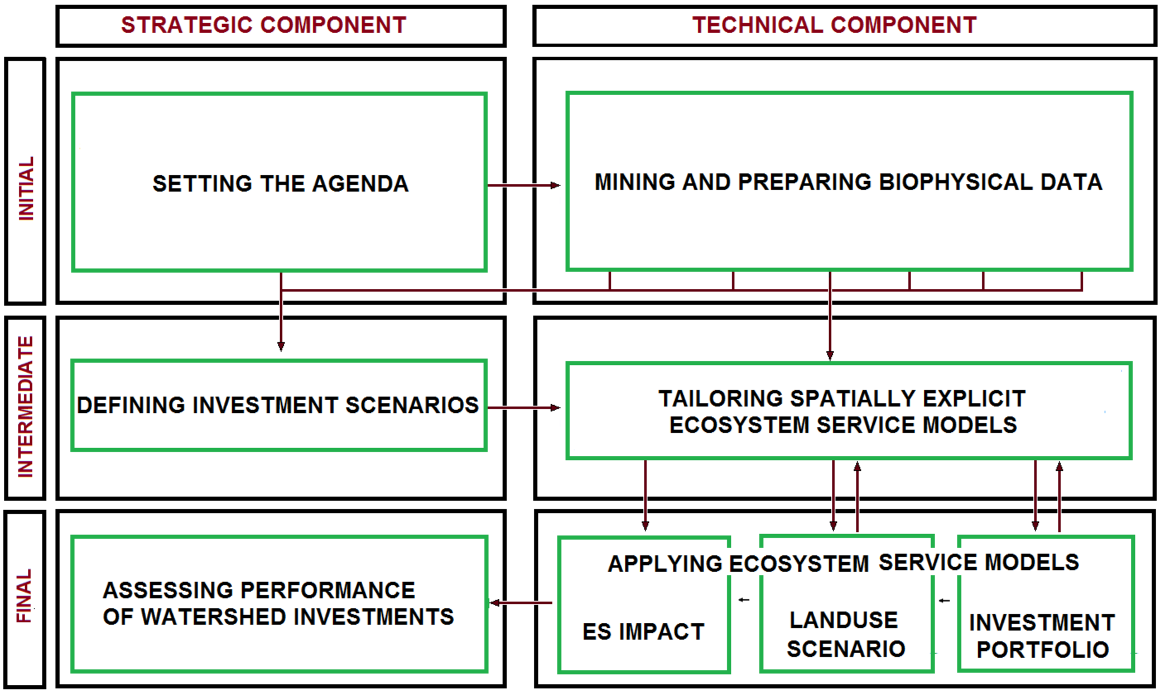


Figure 4.4: A proposed two-component and three-stage, process-based operative approach for designing and assessing impact of watershed investments, building on the concepts of ecosystem services and boundary works.

4.4.1 Setting the agenda

This is perhaps the most crucial step of the process of design and assessment of watershed investments; mainly its aim is to ensure saliency and legitimacy in the eyes of stakeholders. Following are four different types of inputs, which are believed to be the most significant in the context of agenda setting.

4.4.1.1 Defining investment objectives and planning horizon

Numerous factors contribute to defining investment objectives, including legal limitation and standards, empirical evidences, stakeholders' negotiations, and experts' opinion (Vogl et al. 2015). As seen in the previous chapter, defining objectives provides a good opportunity for enhancing both saliency and legitimacy, by involving as much as needed all stakeholders. For the case study application, however, definition of objectives is based on review of documents about ongoing watershed activities and interviews with key informants (see Box 4.1, Box 4.2 and Box 4.3). Accordingly, two illustrative investment objectives were selected: "Urban Water Security" and "Rural Poverty Alleviation" (see also Section 4.3). As for the planning horizon, it was arguably set to a ten-year period.

4.4.1.2 Characterizing stakeholders

Identifying and characterizing the stakeholders in a spatially explicit way is a fundamental step. It includes distinguishing between “Impacted” and “Beneficiaries”. The former, comprise those directly affected by activities undertaken within watershed investments (e.g. farmers losing access to protected areas or introducing new agricultural practices). The latter consist of those whose wellbeing the watershed investment considers as a target (e.g. people in cities benefiting from more water, rural communities involved in poverty alleviation). The two categories are not mutually exclusive, such as the case of rural communities that lose access to protected area, but at the same time, benefit from poverty alleviations measures. Defining, in a more detailed way, “who was who” and their role in the stakeholders’ negotiation is thus an empirical question left for the specific application of the proposed approach. Moreover, the concept of “service-sheds” (Tallis et al. 2015) is included to add a spatial component to the above given definitions of stakeholders. It consists in ideally “tracking” the flow of ecosystem services that benefit a particular group of people, hence delimitating the geographic areas of production of such ecosystem services (Tallis et al. 2015). “Service-sheds” are an effective tool for highlighting key societal issues such as the sharing of costs for maintaining ecosystem services, and more generally addressing challenges of equity (Lamorgese and Geneletti, 2015). However, tracking ecosystem services is not always feasible or reasonable. In fact, it can be quite cumbersome, when considering the different ways in which groups of people with different socio-economic conditions benefit from ecosystem services (Daw et al. 2011).

In the case study application, as far as soil erosion control is concerned, watersheds represent the actual service-sheds. Therefore, reservoirs and their sub-watersheds were used as, respectively, entry points (who benefits from the reservoir) and spatial units for exploring the linkages between ecosystem services and different groups of beneficiaries. Operatively, the Toker watershed was divided into seven sub-watersheds, corresponding to seven reservoirs that supply the city of Asmara. Hence, the beneficiaries of the reservoirs were identified, distinguishing between urban and rural ones. The former refer to the inhabitants of Asmara while the latter, based on Abraham et al (2009), are the 213 and 300 rural households, benefiting from AdiSheka and AdiNifas_D01 reservoirs respectively (see baseline conditions in Figure 4.3). Moreover, due to lack of spatially explicit data, it was reasonably assumed that urban and rural beneficiaries are uniformly distributed over the city area and the sub-watershed of interest, respectively. This was an acceptable approximation, given the focus of this chapter on the urban-rural divide, and not on the differentiated access to benefits within the city itself. For the analysis, since collecting new socio-economic and demographic data was beyond the scope of this study, this chapter relied on previous surveys, mainly one conducted by Abraham et al (2009).

4.4.1.3 Budgeting watershed investments

Budgeting is perhaps the most critical single factor that characterizes watershed investments. Typically, it is an outcome of complex societal negotiations. Here, a simple but effective approach is proposed, based on linking the valuation of ecosystem services or disservices to specific stakeholders (e.g. loss of storage capacity due to soil erosion, which negatively affects a water utility). The choice stems from a general tendency of stakeholders to strongly prefer avoiding losses to acquiring gains, the so-called "loss aversion" bias (Kahneman and Tversky 1984). A good working example is the renowned case of New York City and the Catskills-Delaware watersheds in which the issue of budgeting was strongly and favorably affected by the adoption of an ES perspective (Turner and Daily 2008). For the Toker watershed case study, it assumed the inhabitants of Asmara, almost entirely reliant on the Toker reservoir, were the most influential and most affected stakeholder. Accordingly, the cost of soil erosion was estimated in terms of the depreciation of asset value. Considering a value of US$44 million for Toker Dam alone, an annual storage capacity loss of 0.5-2% (Abraham et al. 2009) would translate in a reduction of asset value of $220-$880 thousands per year. Therefore, this yearly amount could be used as a science-informed evidence both for budgeting WI and, more strategically, advocating the relevance of investments in the Toker watershed.

4.4.1.4 Selecting watershed activities

This step requires input from knowledgeable stakeholder and experts. Watershed activities needed to be properly characterized in order to determine their potential contribution in meeting specific investment objectives, taking into account also the stakeholders' preferences. In fact, watershed activities may diversely involve and affect different stakeholders; for instance, protecting natural areas limits access to local communities, while improving agricultural management may increase crop yield. Therefore, the process of selection of activities could be an important way of fostering a "meaningful communication" among stakeholders, thus contributing to ensure both saliency and legitimacy (Cash et al. 2003, Clark et al. 2011). For the case study application, four relevant activities were select based on ongoing initiatives. Namely, (i) Restoration through assisted revegetation, where native trees are planted in degraded areas; (ii) Protection of native vegetation, to limit deforestation; (iii) Terracing, to reduce erosion in steep areas, and (iv) Agricultural vegetation management, involving farmers in erosion control measures through voluntary agreements.

Having defined the four most significant inputs for setting the agenda (i.e. objective definition, stakeholders' characterization, budgeting, and activities selection), the following step consists in synthesizing these inputs, hence, in proceeding with their operationalization. This is a highly case specific step. In the Toker watershed case study, the first objective of watershed investment (i.e. Urban Water Security) aimed at decreasing sediment yield to reservoirs; accordingly, ecosystem service modeling (i.e. RIOS) was applied to design investment portfolios, based on a criterion of cost-effectiveness or pre-allocation to a single activity, only. Likewise, RIOS was applied for the second objective (i.e. Rural Poverty Alleviation) as well; yet, this time new spatial constraints that defined investment priority areas were duly added. In these areas watershed activities is to be preferred or avoided, irrespective of their cost-effectiveness. For instance, in the case study, activities in the AdiSheka and AdiNifas_D01 sub-watersheds were prioritized, assuming that rural communities could benefit from investment both in terms of poverty reduction (e.g. financial resources that integrate their livelihood in exchange of maintenance of ecosystem services) and poverty prevention (e.g. erosion control that increases crop and livestock yield).

4.4.2 Defining investment scenarios

This step defines investment scenarios, in order to address key questions, such as "how does budget level affect the outcomes of watershed investment?", "what is the most cost-effective combination of activities, for a given budget?", and "what if the whole budget is allocated to a single activity?" and so on. In the proposed approach, scenarios are defined based on three elements, namely, (i) watershed investment objective, (ii) budget level and (iii) budget allocation modality. Importantly, each investment scenario should be discriminated in terms of its desirability and/or feasibility, through a meaningful participation of the stakeholders. This is vital step for comparing various investment scenarios (See Section 4.4.3). In the case study, after the budgetary consideration in (Section 4.4.1.3) and different stakeholders' willingness to invest, six illustrative annual budget levels were identified: \$10.000, \$50.000, \$100.000, \$250.000, \$500.000, and \$1.000.000. In terms of budget allocation between activities, two different modalities were applied, namely, cost-effectiveness based allocation and pre-allocation of the entire budget to a single activity at a time. Therefore, the total number of scenarios that could generated could be expressed as (1+n) * m * k, where n, m, and k were the number of activities, budget levels, and objectives, respectively. In the case of the Toker watershed, 60 possible scenarios were considered, resulting from (1 + 4 activities) × six budget levels× two watershed investment objectives.

4.4.3 Assessing performance of watershed investments

This step aims at supporting stakeholders, especially decision-makers, by computing quantitative assessment of the performance of various watershed investments. In the proposed approach, performance is assessed in terms of the change occurring in selected ecosystem services, expressed in their biophysical or economic values, with respect to baseline conditions. Worth mentioning is how performance assessment needed to be coupled with the previous characterization of investment scenarios, based on feasibility and stakeholders' preference (Section 4.4.2). This can be a good strategy for enhancing the effectiveness of the here proposed operative approach. In the Toker watershed case study, soil erosion reduction was used as an indicator of performance. For the 60 possible investment scenarios and at sub-watershed level, the percentage reduction of soil erosion was calculated with respect to the baseline conditions. This decrease corresponded to an increase of the ecosystem service (i.e. soil erosion control), which is a combined effect of a reduction in sediment export and an increase of retention in the watershed (see model description in Vogl et al. 2015). In any case, the comparison between scenarios is supported by spatially explicit data from the technical component, such as maps of activities, future land use scenarios, and impact on selected ESs (see Section 4.4.6).

4.4.4 Preparation and processing of biophysical data

The initial stage of the technical component deals with preparation and processing of biophysical data, based on the investment objectives. As such, it is entirely dependent on the agenda set as part of the strategic component (see Section 4.4.1). In particular, this stage has a significant role in ensuring scientific credibility of the approach and its outputs. In the Toker watershed case study, both the investment objectives were related to soil erosion. Therefore, based on the methods that are implemented in RIOS, the input data that are needed include: land use and land cover (LULC), digital elevation model (DEM), rainfall erosivity, soil erodibility, soil depth, USLE C factor, and landscape factor (Vogl et al. 2015).

The Toker watershed case study was consciously selected knowing that data paucity and resource scarcity were two important challenging factors. As far as data paucity was concerned, this challenge was faced by relying mainly on databases (e.g. Aster GeDEM) and software tools (e.g. uDig) that are accessible online and cost-free. By way of example, I here mention the use of a 30m resolution DEM (MET and NASA 2011(Tarekegn et al. 2010).

Table 4.2 summarizes the main biophysical data, their sources, and provided hints on their pre-processing. A full description of the ecosystem service models, including information on their assumptions and limitations, and data pre-processing can be found in Sharp et al. (2015) and Vogl et al. (2015).

Table 4.2: Biophysical data for ecosystem service modelling (type, source, preparation and processing).

Data	Source	Reference	Note
LULC	Africover	FAO GEONETWORK. Spatially Aggregated Multipurpose Landcover Database for Eritrea - AFRICOVER (GeoLayer). (Latest update: 18 Feb 2014) Accessed (21 May 2015). URI: http://data.fao.org/ref/7d456921-5365-4958-8482-799de81dc8af.html?version=1.0	Africover land use and land cover was reclassified using the General LULC classification proposed in RIOS Approach (Vogl et al 2015).
DEM	Aster Gedem	METI and NASA (2011) ASTER GDEM Version 2. Accessed (2014). URL:http://gdem.ersdac.jspacesystems.or.jp/	Hydro-geomorphic analysis using “uDig Spatial Tool box” described in (Abera et al. 2014).
Rainfall erositity	-	Vrieling et al 2010, 2014	Rainfall Erosivity is obtained from (Vrieling et al. 2010, 2014) based on 3-hourly TRMM Multi-satellite Precipitation Analysis (TMPA) precipitation data.
Soil erodibility and Soil depth	HWSD	FAO, IIASA, ISRIC, ISSCAS, and JRC. (2012). Harmonized World Soil Database (version 1.2). FAO, Rome, Italy and IIASA, Laxenburg, Austria.	Obtained following the analysis described in http://forums.naturalcapitalproject.org/index.php?p=/discussion/comment/1384/#Comment_1384; (last accessed 21/05/2015)

4.4.5 Tailoring ecosystem service-based models

At the core of the technical component, there are the two software tools based on ecosystem services: RIOS 1.1.8 and InVEST 3.2.0. The former applies a relative-ranking approach, based on important biophysical factors that drive the ecosystem service (Vogl et al. 2015); and was used for designing investment portfolios as well as generating future land use scenarios (Section 4.4.6.1, and 4.4.6.2). The latter modeled the impacts on selected ecosystem services (Section 4.4.6.3).

Figure 4.5 above and in Appendix 3 summarize the rationale behind the RIOS approach, of which a full description, including information on assumptions and limitations, can be found in Vogl et al. (2015). Appendix 3 in particular show a flow diagram of how data is analyzed in “RIOS Investment Portfolio Advisor”. In the RIOS approach, watershed investments target directly a range of activities (now), to trigger a relatively finite set of changes in the watershed, ultimately causing a desired transition in land use and management (in the future). Such transitions affect many of the processes that regulate hydrologic processes and biodiversity, such as water infiltration rates, soil storage capacity, vegetation cover and structure as well as the maintenance of habitat quality and feeding and breeding resources for species (Vogl et al 2015). Ultimately, they affect future land use and related ecosystem services, thus contributing to meeting specific watershed investment objectives.

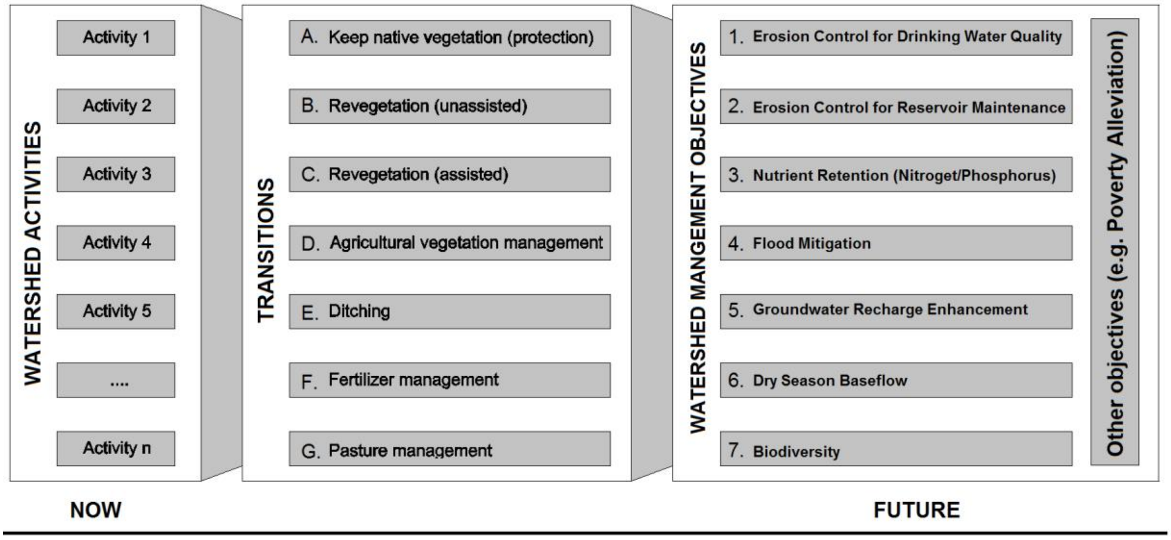


Figure 4.5: Rationale behind the RIOS approach - Investing in watershed activities now to trigger transitions in the land use and management, thus meeting investment objectives in the future.

Technically, RIOS supports any type of activity at landscape-level, but it does not include grey infrastructure solutions such as check dams and retaining walls. Moreover, each activity must map to one of seven supported transitions, shown in Figure 4.5. Namely, keeping native vegetation (i.e. retaining vegetation likely be lost); assisted or unassisted revegetation (i.e. revitalizing vegetation on degraded lands with or without out active interventions); agricultural vegetation management (i.e. increasing crop structure, coverage and/or diversity); ditching (i.e. improving infiltration and slowing sediment and nutrients transport); fertilizer management (i.e. changing fertilizer application); and pasture management (i.e. changing management practices). Likewise, RIOS supports seven ecosystem service-related objectives, shown in Figure 4.5, with possibility of including additional objectives, such as poverty alleviation, defined by the user outside of RIOS.

Shown in Table 4.3 and Table 4.4 are three critical inputs in the RIOS approach, namely, the so-called “transition potentials” and “objective-transition weights” and “activity’s unit cost”. The first input defines which activities cause which transitions; the second input specifies the relative contribution of each transition to the objective of the watershed investment and the last refers to the overall cost unitary cost of each activity. Similarly, Table 4.5 present another important input, dealing with additional restriction on watershed activities related, for instance, to LULC, slope or elevation.

Table 4.3: "RIOS Investment Portfolio Advisor" input 1- Defining activity's "transition potential" and "unit cost"

Watershed activity	Transition	unit cost
Agricultural vegetation management	D - Agricultural vegetation management	US$/ha 125
Protection	A - Keep native vegetation	US$/ha 125
Restoration assisted	C - Revegetation (assisted)	US$/ha 1010
Terracing	E - Ditching	US$/ha 310

Table 4.4: "RIOS Investment Portfolio Advisor" input 2– Defining activity's "objective – transition weight"

Watershed activity	Transitions						
	A	B	C	**D**	**E**	**F**	**G**
Agricultural vegetation management				1			
Protection	1						
Restoration assisted			1				
Terracing					1		

A - Keep native vegetation
B – Revegetation (unassisted)
C - Revegetation (assisted)
D - Agricultural vegetation management
E – Ditching
F- Fertilizer management
G – Pasture management

Table 4.5: "RIOS Investment Portfolio Advisor" input 3 – Defining additional landuse- and slope-based constraints on activities.

LULC	Ag-mgmt.	Protection	Restoration	Terracing§
Tropical mixed agriculture	Yes	-	Yes	Yes
Permanent crops	Yes	-	-	-
Mixed forest, agriculture	Yes	-	Yes	-
Tropical evergreen forest	-	Yes	Yes	-
Open water	-	-	-	-
Mixed urban	-	-	-	-
Floodplain forest	-	Yes	Yes	-

§ No terracing for slope less than 12%

Indeed, local knowledge and experience is preferred to better characterize watershed activities. This is particularly valuable for ensuring saliency and legitimacy during the process of design and assessment of watershed investments, and beyond. Owing to lack of local data, however, most inputs used in RIOS were obtained also from online databases, such as the Harmonized World Soil Database (HWSD), and studies conducted elsewhere (e.g. unit costs of activities adopted from an ongoing Water Fund in Kenya).

4.4.6 Applying ecosystem service-based models

4.4.6.1 Designing investment portfolio with RIOS

For each investment scenarios, RIOS module "Investment Portfolio Advisor" was applied to coherently combine biophysical and socio-economic input data from the above sections, in order to design a set of investment portfolios (See Appendix 3). An investment portfolio consists of a spatially explicit allocation of the overall budget between the watershed activities. For a given scenario (i.e. objective, budget level, budget allocation modality), it defines which activities, when during the planning horizon, and where in the watershed are the most cost effective. For instance, in the application to Toker watershed case study, up to 600 maps of activities could be generated: the number of scenarios (60) multiplied by the number of years considered as planning horizon (10).

4.4.6.2 Generating future land use scenarios with RIOS

For each investment portfolio, the RIOS module "Portfolio Translator" was applied to generate a future land use scenarios. Land use scenarios represent the future condition of the watershed, where RIOS-selected watershed activities were implemented and embedded into the map of LULC. More specifically, for each existing LULC type, it was specified which new LULC would result from a specific transition (see Table 4.6). It is worth noticing here that some transitions (e.g. assisted revegetation) would imply an actual land use change, while others (e.g. ditching) would result in a change of the biophysical parameters that affect soil erosion control such as sediment retention, sediment export, USLE crop factor, as shown in Table 4.7 (Vogl et al. 2015). Moreover, for each transition, the "Proportional Transition Factor – PTF" was defined. The PTF is an important parameter used in RIOS Portfolio Translator. With a value between 0 and 1, it specifies what proportion of the baseline LULC is likely to be transitioned to the new LULC at the end of the planning horizon. In the case study application, the PTF was reasonably set to 0.65 or 0.20: the lower value refers to the least probable transitions (see Table 4.6). However, these were assumptions based on expert opinion, not confirmed by stakeholders and local experts.

Table 4.6: "RIOS Portfolio Translator" input 1 - Parameters for generating future land use scenario (Which land use change occur due to a transition? To what extent, i.e. what is Proportional Transition Factor –PTF?)

Old LULC	Transition Type	New LULC	PTF
tropical mixed agriculture	Agric. veg. management	tropical corn	0.65
permanent crops	«	tropical corn	0.65
mixed forest, agriculture	«	mixed forest, agriculture, pasture	0.65
tropical evergreen forest	Protection (failed)	alfaalfa	0.65
floodplain forest	«	alfaalfa	0.65
tropical mixed agriculture	Revegetation (assisted)	conifer forest or woodland	0.65
tropical mixed agriculture	«	floodplain forest	0.20
mixed forest, agriculture	«	conifer forest or woodland	0.65
tropical mixed agriculture	Ditching	tropical corn	0.65

Table 4.7: Biophysical parameters characterizing different land uses.

LULC	Sediment export	Sediment retention	USLE C
tropical mixed agriculture	0.190	0.840	0.190
permanent crops	0.190	0.840	0.190
mixed forest, agriculture	0.097	0.795	0.097
tropical evergreen forest	0.003	0.75	0.003
floodplain forest	0.001	0.870	0.001
tropical corn	0.080	0.840	0.080
mixed forest, agriculture, pasture	0.111	0.810	0.111
alfalfa	0.190	0.840	0.190
conifer forest or woodland	0.003	0.680	0.003

4.4.6.3 Modelling impact on selected ecosystem services with InVEST

This is the last step of the technical component; it deals with modeling the impacts on selected ecosystem services, considering the future land use scenarios and respective biophysical parameters. For the Toker watershed case study, the impact on soil erosion control was modeled using the InVEST 3.2.0 (Sharp et al. 2015). The seven sub-watershed in the Toker watershed were used as spatial units of analysis and service-sheds. For each scenario, soil erosion per unit area in hectares was evaluated, at sub-watershed level. Following the percentage change was calculated with respect to the baseline conditions, defined by the existing land use and respective biophysical parameters in the Toker watershed. Hence, this information was used in the last stage of the Strategic component, to assess the performance of watershed investments (see Section 4.4.3). This represents the closure of a first round of a dynamic process of negotiation among stakeholders.

4.5 Results

The case study application resulted in a relatively large number of intermediate (i.e. requiring further processing) and final outputs. For instance, the definition of investment scenario was crucial for designing investment portfolios that were then used for generating future land use scenarios and their respective biophysical parameters, which in turn represented the main inputs for modeling impacts on ecosystem services. However, the main scope here was to highlight how the proposed approach can support the process of stakeholder negotiations, rather than presenting the results of each step of the proposed approach. Therefore, and for the sake of readability, in the remainder of this chapter three illustrative results were selected, in order to address the three specific questions of this chapter (see section 4.1). Mainly the focus was on the last stage of both the technical and strategic component of the proposed approach (i.e. watershed investment portfolios, impact on ecosystem services, and performance of watershed investments).

4.5.1 Watershed investment portfolios

Figure 4.6 shows the 60 possible investment scenarios for the case study. They represent the two watershed investment objectives, six budget levels, and two budget allocation modalities (i.e. cost-effectiveness and pre-allocation to a single activity at a time). Nevertheless, only 38 of these investment scenarios were actually investigated; in fact, the remaining 22 were found to be unfeasible because of some circumstantial and biophysical factors. For instance, areal extension of native vegetation in the Toker watershed was so small that, a limited budget ($10.000) sufficed to cover the whole area. In other cases, increased budget level did not result in a change of selected ecosystem services.

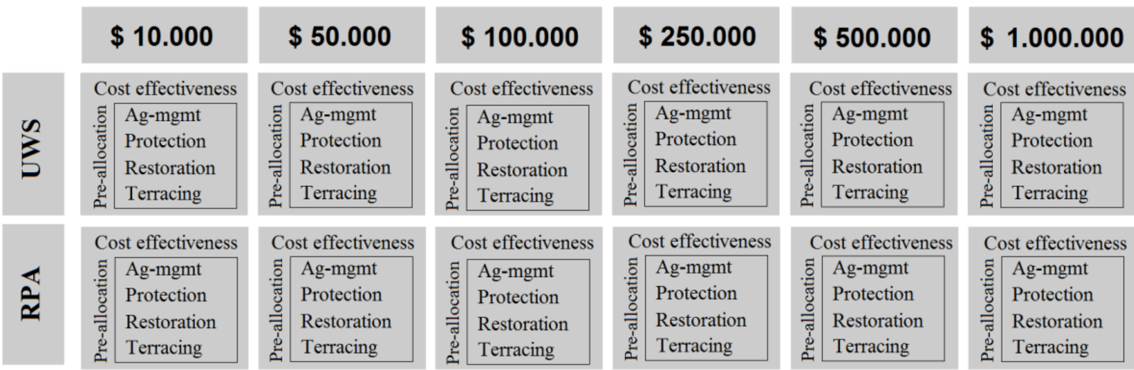


Figure 4.6: Sixty different investment scenario in the Toker watershed, representing two investment objectives (UWS - Urban water security and RPA - Rural poverty alleviations), six budget levels and two budget allocation modalities.

Figure 4.7 compares, by way of example, two investment portfolios related to urban water security (upper panel) and rural poverty alleviation (lower panel). Both investment portfolios refer to an annual budget of US$100.000 and budget allocation based on cost-effectiveness. It is possible to compare the yearly progress of the investment portfolios, with colors representing different watershed activities. Accordingly, both portfolios invested in only two types of activities (i.e. agricultural vegetation management and protection), which also happened to be the least expensive ones (US$125 per ha against US$310 per ha for terracing or US$1010 per ha for restoration). Spatially, in both cases watershed activities tended to concentrate along the river networks, which was coherent with a generally higher cost-effectiveness of investments in riparian buffers. In the case of rural poverty alleviation, however, there was a marked preference of activities in the two priority sub-watersheds (i.e. AdiSheka and AdiNfas_D01), which were almost entirely covered, by the end of the ten-year planning period.

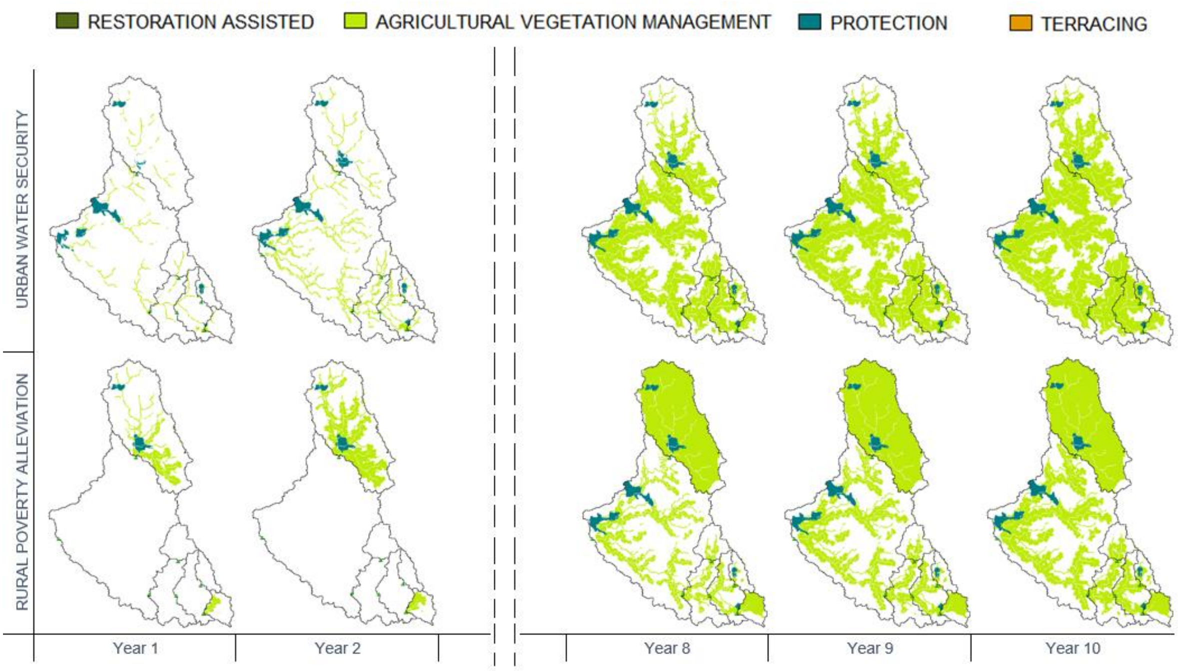


Figure 4.7: Illustrative comparison of the yearly progress of two investment portfolios, aiming at urban water security and rural poverty alleviation (annual budget of $100.000, allocated cost-effectively).

Figure 4.8 shows another illustrative result, aiming to explore the role of the overall budget in shaping the investments portfolios. The example refers to scenarios in which the budget was allocated to assisted restoration, only. Here, worth noticing was the marked spatial mismatch between investment portfolios aiming at the two investment objectives.

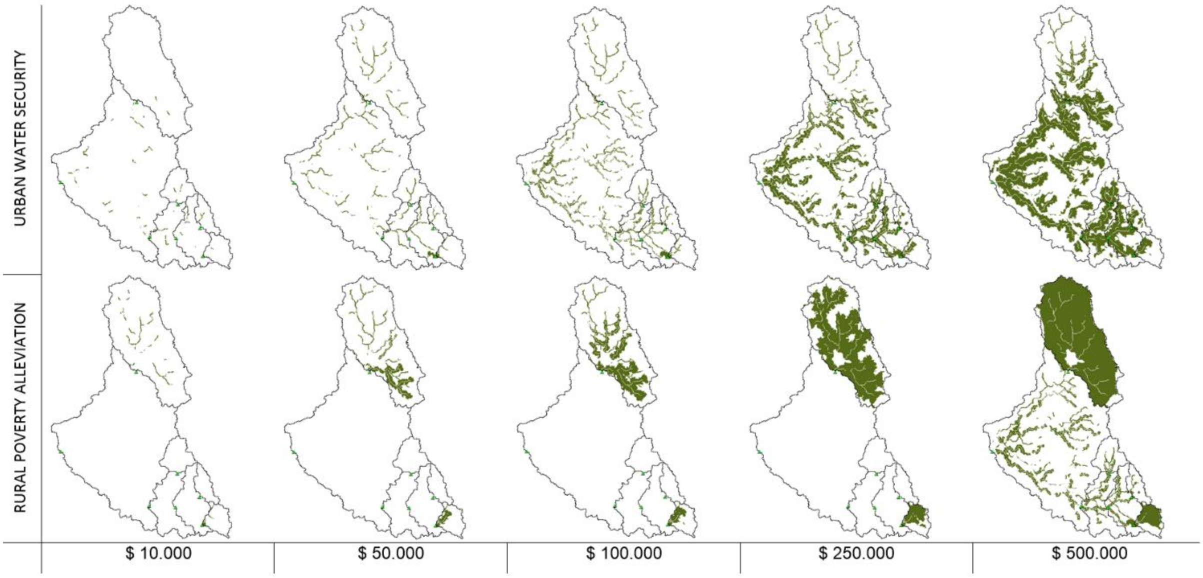


Figure 4.8: Illustrative comparison of ten investment portfolios that consider two investment objectives and five budget levels (budget entirely pre-allocated to assisted restoration).

Finally, Table 4.8 and Table 4.9 synthesize all the 38 investment portfolios in the case study application, 19 for each WI objective. For each scenario, the table specified the budget allocated to each activity as well as the areal extension covered by the activity.

Table 4.8: Synthesis of investment portfolios for urban water security (activity, allocated budget and areal extension).

		A		B		C		D		E	
	Activity	Budget	Area	Budget	Area	Budget	Area	Budget	Area	Budget	Area
$100.000	Ag-mgmt.	$56,846	454.8	$99,900	799.2	-	-	-	-	-	-
	Protection	$43,054	344.4	-	-	$57,881	463.1	-	-	-	-
	Rest-asst	-	-	-	-	-	-	$99,990	99.0	-	-
	Terracing	-	-	-	-	-	-	-	-	$99,882	322.2
	Total	**$99,900**	**799.2**	**$99,900**	**799.2**	**$57,881**	**463.1**	**$99,990**	**99.0**	**$99,882**	**322.2**
$500.0000	Ag-mgmt.	$442,564	3540.5	$499,950	3999.6			-	-	-	-
	Protection	$57,386	459.1	-	-			-	-	-	-
	Rest-asst	-	-	-	-			$499,950	495.0	-	-
	Terracing	-	-	-	-			-	-	$499,968	1612.8
	Total	**$499,950**	**3999.6**	**$499,950**	**3999.6**			**$499,950**	**495.0**	**$499,968**	**1612.8**
$1.000.000	Ag-mgmt.	$942,244	7538.0	$999,900	7999.2			-	-	-	-
	Protection	$57,656	461.3	-	-			-	-	-	-
	Rest-asst	-	-	-	-			$999,900	990.0	-	-
	Terracing	-	-	-	-			-	-	$999,936	3225.6
	Total	**$999,900**	**7999.2**	**$999,900**	**7999.2**			**$999,900**	**990.0**	**$999,936**	**3225.6**
$2.500.0000	Ag-mgmt.	$1,523,903	12191.2	$1,523,903	12191.2			-	-	-	-
	Protection	$57,814	462.5	-	-			-	-	-	-
	Rest-asst	-	-	-	-			$2,499,750	2475.0	-	-
	Terracing	-	-	-	-			-	-	$1,885,956	6083.7
	Total	**$1,581,716**	**12653.7**	**$1,523,903**	**12191.2**			**$2,499,750**	**2475.0**	**$1,885,956**	**6083.7**
$5.000.000	Ag-mgmt.							-	-		
	Protection							-	-		
	Rest-asst							$4,999,500	4950.0		
	Terracing							-	-		
	Total							**$4,999,500**	**4950.0**		
$10.000.000	Ag-mgmt.							-	-		
	Protection							-	-		
	Rest-asst							$9,999,909	9900.9		
	Terracing							-	-		
	Total							**$9,999,909**	**9900.9**		

Budget allocation modes: A cost-effectiveness, B agricultural vegetation management; C protection; D terracing; E restoration assisted
Greyed boxes represent the 11 unfeasible scenarios (see Section 4.5.1)

Table 4.9: Synthesis of investment portfolios for rural poverty alleviation (activity, allocated budget and areal extension).

		A		B		C		D		E	
	Activity	Budget	Area	Budget	Area	Budget	Area	Budget	Area	Budget	Area
$100.000	Ag-mgmt.	$83,711	669.7	$99,900	799.2	-	-	-	-	-	-
	Protection	$16,189	129.5	-	-	$57,881	463.1	-	-	-	-
	Rest-asst	-	-	-	-	-	-	$99,990	99.0	-	-
	Terracing	-	-	-	-	-	-	$0	0.0	$99,882	322.2
	Total	**$99,900**	**799.2**	**$99,900**	**799.2**	**$57,881**	**463.1**	**$99,990**	**99.0**	**$99,882**	**322.2**
$500.0000	Ag-mgmt.	$453,746	3630.0	$499,950	3999.6			-	-	-	-
	Protection	$46,204	369.6	-	-			-	-	-	-
	Rest-asst	-	-	-	-			$499,950	495.0	-	-
	Terracing	-	-	-	-			$0	0.0	$499,968	1612.8
	Total	**$499,950**	**3999.6**	**$499,950**	**3999.6**			**$499,950**	**495.0**	**$499,968**	**1612.8**
$1.000.000	Ag-mgmt.	$942,278	7538.2	$999,900	7999.2			-	-	-	-
	Protection	$57,623	461.0	-	-			-	-	-	-
	Rest-asst	-	-	-	-			$999,900	990.0	-	-
	Terracing	-	-	-	-			$0	0.0	$999,936	3225.6
	Total	**$999,900**	**7999.2**	**$999,900**	**7999.2**			**$999,900**	**990.0**	**$999,936**	**3225.6**
$2.500.0000	Ag-mgmt.	$1,523,903	12191.2	$1,523,903	12191.2			-	-	-	-
	Protection	$57,780	462.2	-	-			-	-	-	-
	Rest-asst	$545	0.5	-	-			$2,499,750	2475.0	-	-
	Terracing	-	-	-	-			$0	0.0	$1,885,956	6083.7
	Total	**$1,582,228**	**12654.0**	**$1,523,903**	**12191.2**			**$2,499,750**	**2475.0**	**$1,885,956**	**6083.7**
$5.000.000	Ag-mgmt.							-	-		
	Protection							-	-		
	Rest-asst							$4,999,500	4950.0		
	Terracing							$0	0.0		
	Total							**$4,999,500**	**4950.0**		
$10.000.000	Ag-mgmt.							-	-		
	Protection							-	-		
	Rest-asst							$9,999,909	9900.9		
	Terracing							$0	0.0		
	Total							**$9,999,909**	**9900.9**		

Budget allocation modes: A cost-effectiveness, B agricultural vegetation management; C protection; D terracing; E restoration assisted
Greyed boxes represent the 11 unfeasible scenarios (see Section 4.5.1)

4.5.2 Performance of watershed investments

For the 38 scenarios, Table 4.10 shows how each investment portfolio performed at both sub-watershed and watershed level (i.e. grayed cells). Here, performance is expressed in terms of percentage reduction of soil erosion, with respect to the baseline conditions of the Toker watershed. For each investment objective, Table 4.10 helps explore the effect of different budget levels, and modalities of budget allocation (cost-effectiveness or single activity at a time). It allowed comparing, in a simple and rapid way, the performance of investment portfolios, at sub-watershed (first 7 rows) and watershed level (last row, grayed).

For instance, in the case of investment for urban water security and an overall budget of $100.000, the perceptual reduction of soil erosion, at watershed level, was of 15.3% (cost-effectiveness), 19.7% (agricultural vegetation management), 6.6% (assisted restoration), and 9% (terracing). This reflected, among others, the role of the unit cost and effectiveness of the activities. Moreover, Table 4.10 allowed comparing investments aimed at the two objectives, for instance, by calculating the difference in performance. A similar analysis showed that, at watershed level, especially for higher budget levels, the difference tended to be null, and in any case less than four percent. This was an important piece of information, which would need further investigation. A possible explanation could be simply that at higher budget levels such large portions of the watershed were covered for both objectives, while at lower budgets, the overall impact of the investments was minimum.

However, when making any comparison based on Table 4.10, it is worth bearing in mind that, for a given budget level, the money actually invested could differ based on the scenario. Above all, it is should be recalled that all our analysis were based on uncalibrated models and some assumptions regarding the unit costs of activities. Indeed, another area for further stakeholder input could involve obtaining observed data for calibration and validation of results, as well as data on cost of activities and their effectiveness.

Table 4.10: Synthesis of performance of watershed investments: percentage reduction of soil erosion at sub-watershed level.

		URBAN WATER ECURITY						RURAL POVERTY ALLEVIATION					
	ID	**$10**	**$50**	**$100**	**$250**	**$500**	**$1000**	**$10**	**$50**	**$100**	**$250**	**$500**	**$1000**
Cost-effectiveness	Toker	-0.7%	2.6%	-10.1%	-24.5%			3.3%	-6.1%	-15.8%	-24.5%		
	AdiSheka	-5.5%	-29.0%	-29.6%	-32.2%			-0.3%	-4.0%	-17.4%	-32.2%		
	Maisirwa	-2.8%	-8.7%	-14.1%	-28.6%			-0.3%	-5.3%	-14.0%	-28.6%		
	Beleza	-2.3%	-7.6%	-18.9%	-33.8%			0.4%	1.6%	1.6%	0.9%		
	Valle-Gnocchi	0.0%	-0.4%	1.2%	0.9%			-1.6%	-10.0%	-24.3%	-33.8%		
	AdiNifas_Do1	0.4%	0.4%	0.4%	0.4%			0.4%	0.4%	0.4%	0.4%		
	AdiNifas_D02	0.0%	4.9%	5.0%	5.0%			5.0%	5.0%	5.0%	5.0%		
	Total	-2.2%	-7.3%	-15.3%	-25.4%			1.8%	-5.0%	-15.2%	-25.4%		
Agri. Veg. management	Toker	-0.8%	-2.6%	-16.6%	-29.6%			-2.1%	-12.4%	-21.8%	-29.6%		
	AdiSheka	-8.3%	-30.5%	-31.1%	-33.6%			-1.6%	-6.8%	-20.3%	-33.6%		
	Maisirwa	-2.3%	-8.9%	-15.0%	-28.6%			-0.7%	-6.2%	-15.5%	-28.6%		
	Beleza	-2.7%	-8.7%	-20.5%	-33.8%			0.0%	0.0%	0.0%	-0.7%		
	Valle-Gnocchi	0.0%	-0.4%	-0.4%	-0.7%			-2.5%	-11.9%	-25.8%	-33.8%		
	AdiNifas_Do1	0.0%	0.0%	0.0%	0.0%			0.0%	0.0%	0.0%	0.0%		
	AdiNifas_D02	0.0%	0.0%	0.0%	0.0%			0.0%	0.0%	0.0%	0.0%		
	Total	-3.0%	-10.9%	-19.7%	-28.8%			-1.7%	-9.7%	-19.7%	-28.8%		
Protection	Toker	5.0%						5.0%					
	AdiSheka	1.4%						1.4%					
	Maisirwa	0.0%						0.0%					
	Beleza	0.0%						1.6%					
	Valle-Gnocchi	1.6%						0.0%					
	AdiNifas_Do1	0.4%						0.4%					
	AdiNifas_D02	5.0%						5.0%					
	Total	3.4%						3.4%					
Assisted restoration	Toker	-0.1%	-53.5%	-58.9%	-69.8%	-75.7%	-36.0%	-0.4%	-1.9%	-4.1%	-12.2%	-23.8%	-41.7%
	AdiSheka	-1.4%	-89.8%	-90.2%	-90.8%	-91.6%	-53.8%	-0.2%	-2.2%	-2.8%	-5.6%	-18.0%	-44.9%
	Maisirwa	-0.2%	1205.8%	1197.0%	1190.5%	1104.2%	-38.6%	-0.1%	-0.6%	-2.1%	-6.9%	-17.8%	-39.3%
	Beleza	-0.6%	31.5%	31.5%	31.3%	30.7%	-0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
	Valle-Gnocchi	0.0%	-54.6%	-54.6%	-54.6%	-54.6%	-48.1%	-1.1%	-3.1%	-5.5%	-12.1%	-26.3%	-52.0%
	AdiNifas_Do1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	AdiNifas_D02	0.0%	132.8%	123.2%	105.7%	87.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Total	-0.5%	-2.9%	-6.6%	-13.6%	-21.4%	-39.1%	-0.3%	-1.8%	-3.4%	-9.2%	-20.3%	-40.0%
Terracing	Toker	-0.4%	-57.9%	-59.1%	-60.0%			-0.9%	-5.4%	-9.3%	-14.9%		
	AdiSheka	-3.5%	-90.1%	-90.3%	-91.1%			-1.0%	-3.0%	-9.7%	-20.4%		
	Maisirwa	-1.4%	1208.6%	1145.7%	1022.4%			-0.2%	-3.3%	-6.7%	-17.2%		
	Beleza	-1.5%	31.4%	31.1%	30.8%			0.0%	0.0%	0.0%	-0.5%		
	Valle-Gnocchi	0.0%	-54.6%	-54.6%	-54.6%			-0.8%	-3.5%	-8.8%	-14.7%		
	AdiNifas_Do1	0.0%	0.0%	0.0%	0.0%			0.0%	0.0%	0.0%	0.0%		
	AdiNifas_D02	0.0%	130.7%	124.7%	101.2%			0.0%	0.0%	0.0%	0.0%		
	Total	-1.3%	-5.4%	-9.0%	-15.5%			-0.8%	-4.2%	-8.7%	-15.5%		

4.6 Discussion

4.6.1 General consideration

The proposed approach built on some innovative frameworks and tools (RIOS, InVEST) and lessons learned by the Natural Capital Project, mainly within the so-called Water Funds. These are a good working example of watershed investments that advance an effective operationalization of the ecosystem services approach. The proposed approach used spatially explicit analysis and modeling of ecosystem services to design investment portfolios, generate future land use scenarios, and model impacts on selected ecosystem services. Thus, it contributed to the growing literature on the interactions between land use changes and the provision of ecosystem services (Nelson et al. 2006, Polasky et al. 2008, Geneletti 2013). In particular, it addressed some of the main hindrances to the operationalization of an ecosystem services approach. According to Turner and Daily (2008), the three main hindrances are: "information failure", i.e. lack of detailed information at scales relevant to decision-making; "market failure", i.e. lack of compelling models of success, aligning economic incentives with conservation; and "institutional failure", lack of practical know-how in the process of institutional design & implementation. Through a case study approach, this research directly addressed the "information failure" by properly answering some key management questions; at the same time, it indirectly contributed to facing the other two failures. For instance, by adopting a simple approach for budgeting that accounts for the loss aversion bias of stakeholders.

Moreover, the proposed approach drew from the literature on boundary work (Cash et al 2003, Clark et al 2011), and more generally bridging organizations (Folke et al, 2005, Olsson et al 2007, Kowalski and Jenkins 2015). Mainly, it referred to the generalized framework for boundary work, proposed by Clark et al. 2011, which provided guidance on how diverse stakeholders may collaboratively generate knowledge for adaptive ecosystem management, and establish good working relations to promote cooperative implementation. In fact, the here proposed operative methodology built on our empirical findings about boundary work in adaptive watershed management for ES, presented in Chapter 3. Here mentioned is the distinction between two components (strategic and technical) and three stages, which reflect the different needs of boundary work, in order to facilitate negotiation among stakeholders engaged in knowledge use and production. The strategic component mainly ensured saliency and legitimacy, while the technical component ensured credibility. Yet, the two components were tightly interlinked; only jointly did they actually contribute to a successful implementation of watershed investments, by linking diverse sets of stakeholders and knowledge systems, across different management levels and across sectors (Kowalki and Jenkins, 2015). Ultimately, the emphasis on boundary work in the proposed approach was expected to contribute to creating "an arena of knowledge coproduction, trust building, sense making, learning, vertical and horizontal collaboration and conflict resolution" (Kowalki and Jenkins, 2015). Yet, as Parker and Corona (2012) put it, boundary work is part of a dynamic process that takes place in a "landscape of tensions", rather than a single-time achievement.

Finally, general considerations pointed to soil erosion and water scarcity as two common socio-ecological challenges affecting many cities in the Global South. This made utterly difficult accomplishing to their mission of securing water to their population and eventually addressing rural poverty. Thus, the relevance of our empirical application also lies in illustrating the applicability of the proposed approach to the case of medium-sized cities and cities with less than 1 million inhabitants that more than often lack adequate financial and institutional capacity. The case study application highlighted the main challenges in terms of data paucity, which indeed affected the results of the analysis, but also boundary work that should be put in place to facilitate the negotiation among stakeholders. In particular, building on real-life experiences and tools developed by the Water Funds, mainly in Latin America, it showed a possible operationalization of the ES approach for watershed management in data-poor contexts in Africa.

Pragmatically, the proposed operative approach can effectively support the design and assessment of the impact of watershed investments that aim at urban water security along with other social or environmental objectives. By addressing stakeholders' concerns of credibility, saliency, and legitimacy, the methodology could facilitate negotiation of objectives, definition of scenarios, and assessment of alternative watershed investments, to face optimally local socio-ecological challenges.

4.6.2 Opportunities for real-life application in the Toker Watershed

In the Toker watershed case study, three watershed initiatives that could represent "windows of opportunity" for applying the proposed approach were identified. The selected initiatives are representative of the contextual and contingent factors as well as the relative influence of stakeholders in the case study area. Hence, by highlighting how each initiative taken singularly could possibly benefit from the here proposed approach, the aim is to trigger possible collaboration, within a framework of adaptive watershed management.

A first initiative and most significant initiative consists of existing partnerships between the water utility that supplies water to the city of Asmara and farmers in the Central Region, in which the Toker watershed is located (see Box 4.1).

EXISTING URBAN –RURAL PARTNERSHIPS IN THE TOKER WATERSHED
Asmara Water Supply provides agricultural extension services to farmers at subzoba branch offices. There are five associations in Central Zone (Zoba Maekel), each having a management committee, consisting of a chairperson, secretary and treasurer. The associations include 1.126 farmer members engaged in: horticultural production, cattle fattening, beekeeping, poultry, and dairy production. Among other things, the Toker Project provides technical and financial support to farmers in the watershed, for instance, by running 10 village shops to ease access to agricultural inputs (fertilizers, chemicals...). The initiative is coordinated by a management committee that consist of representatives of farmers, village administration and the project (NFIS, 2005 as cited by Abraham et al 2009)

Box 4.1: First illustrative initiative in the Toker Watershed. Existing partnership between utility and farmers in the Central Region (source: Abraham et al 2009).

A second initiative is a transdisciplinary research project dealing with water resource management in the Upper Anseba Watershed, which includes the Toker watershed. Among others, the projects developed a sound spatially explicit database, including the position and status of reservoirs, beneficiaries and relevant biophysical data, which had been used in this research. However, it did not explicitly explore potential urban-rural partnerships. It is more concerned with the rural implications of water resources management, overlooking the urban-rural interactions (see Box 4.2).

A third initiative is a so-called Summer Student Work Program (SSWP). Launched by the Ministry of Education (MoE) in 1994, it engages secondary school students in a wide range of activities, including forestation, soil and water conservation, and assisting poor farmers. It is a valuable socio-ecological “experiment”, allowing students with urban background to reconnect to nature and interact with farmers of different social-ethnic-economic extraction. At the same time, it contributes to the restoration of ecosystems and their services, often directly benefiting the rural communities, as well as assists poor farmers. Quite interesting is an assessment of the first 15 years of the SSWP, carried out in 2009. Indeed, it is a milestone of the social learning taking place in terms of watershed management in Eritrea (see Box 4.3).

APPRAISAL OF SURFACE WATER IN UPPER ANSEBA WATERSHED (ASW-UAW)

The "Appraisal of Surface Water in the Upper Anseba Watershed" (ASW-UAW) consists of a transdisciplinary research aiming to create a basis for informed decision-making processes in the use of surface waters in the Central Region, and more specifically the Upper Anseba Watershed. It addressed key shortcomings in: (i) the information required for a more efficient management of surface waters, and (ii) the participation of stakeholders.

Its objective was to assess surface water capacity and management, raise awareness, and build capacity of the major stakeholders. More specifically, to:

A. Create a spatial database, high-resolution satellite image maps to address the shortcomings in the information required as a basis for informed decisions for more efficient management of surface waters, i.e., to fair allocation of resources according to the needs of the population and balanced with the capacity of the catchment to generate the required water resource.
B. Evaluate the general characteristics and problems of reservoirs in Central Region with more emphasis in the Upper Anseba Catchment
C. Assess the extent and efficiency of water use with a focus on the existing irrigation system and estimate the extent of the potential irrigable areas
D. estimate the extent of sediment deposition of selected reservoirs
E. Assess community perceptions & ambitions regarding the reservoirs & their use.
F. Identify promising practices, methodologies and approaches that can be a basis for replication in other catchments as pilot for similar studies and implementation of small projects.

The ASW-UAW was funded by the Eastern and Southern Africa Partnership Programme (ESAPP) and supported by the Swiss Centre for Development and Environment (CDE), within the framework of the Sustainable Land Management Programme, Eritrea (SLM Eritrea).

Box 4.2: Second illustrative initiative in the Toker Watershed. Transdisciplinary research on water resource management in the Central region, focusing on agricultural use (source: Abraham et al 2009).

From a perspective of an adaptive watershed management, the three initiatives provide an interesting "window of opportunity". Singularly, the three initiatives could benefit from the application of the here proposed approach. For the first initiative, partnership between the Asmara water utility and the farmers, by introducing an ecosystem services perspective, the approach has the potential to boost the existing cooperation by shifting it to a higher level (e.g. PES schemes). As for the transdisciplinary research on water resources, the approach could provide an important support by addressing the urban-rural linkages, thus overcoming its abovementioned shortcoming. Finally, for the SSWP, the approach could ensure that its activities are designed based on sound scientific information. In fact, currently the identification of the areas of intervention heavily relies on expert-based approaches, which lack the needed flexibility to form the basis of an iterative science-informed decision support system. Most interestingly, the here proposed approach based on the concepts of ecosystem services and boundary work, can actually trigger a process of social learning that involves the three initiatives, within a framework of adaptive watershed management. In this process, we envisage the water utility in Asmara as a central actor. Accordingly, the question that arises is has the Asmara water utility the needed institutional capacity to play this key role?

SUMMER STUDENT WORK PROGRAM (SSWP)

About the program

Launched by the Ministry of Education (MoE) in 1994, the Student Summer Work Program (SSWP) engages secondary school students in a wide range of activities, including forestation, soil and water conservation, and assisting poor farmers. During 1994-2008, the SSWP had a total cost of US$11 million and took place in 182 location all over the country, of which 17 in the Central Region (Zoba Maekel), where our case study is located.

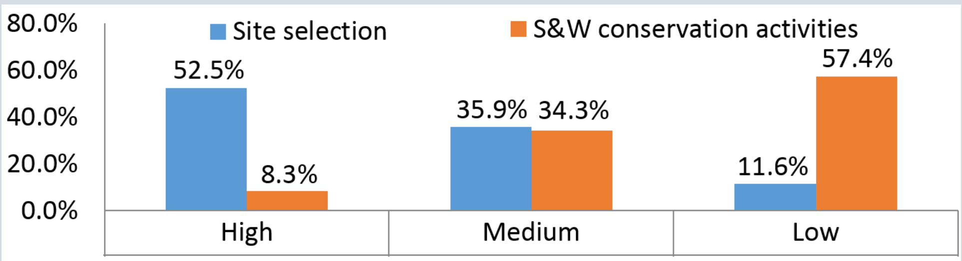
From the perspective of an adaptive watershed management, particularly interesting is a comprehensive assessment of the SSWP carried out by the MoE in 2009. Its main was to assess the level of success of the SSWP, evaluate the perception of students, teachers and villagers and assess the organization and management of the SSWP. It considered 62 out of 187 locations of the campaign, involving 400 students, 400 teachers, 186 villagers and various experts.

Involvement of rural communities

The assessment identified the key criteria used for selecting the sites of intervention as well as analyzed how they relate to the level of success of the SSWP. The selection criteria included top soil depth and type, slope gradient, and management type.

Most interestingly, the assessment highlighted a clear mismatch between participation of farmers in site selection, and actual activities of the SSWP (see graph below). In 53, 36, and 12 percent of the site participation of farmers in site selection was respectively, high, medium, and low. For participation on actual activities, on the other hand, the opposite trend was observed.

Moreover, from the interviews it emerged that farmers were not satisfied with the work done by the students, whom they perceive as being too “urban”. Instead, they argue they could have achieved better results with the same resources of the program, which is a particularly relevant for exploring the willingness of rural communities to take active part in WI related activities.



Participation of the rural communities in site selection and actual S&W conservation activities.

Box 4.3: Third illustrative initiative in the Toker Watershed. Summer Student Work Program and the involvement of rural communities (source: Assessment report by the Eritrean Ministry of Education).

4.7 Conclusion

This chapter built and tested an operative approach to support the design and assessment of watershed investments: a promising opportunity to promote large-scale transformative change that promote human wellbeing while conserving ecosystems, in the near future. The proposed approach utilized the concepts of ecosystem services, mainly in the form of spatially explicit modeling, and boundary work. By addressing concerns of diverse stakeholders, the approach helped facilitate negotiation of objectives, definition of scenarios, and assessment of alternative watershed investments. I believe the approach has good potential to trigger and support the implementation of an adaptive watershed management (Pahl-Wostl et al. 2007, 2011), of which watershed investments can be a strong implementation tool. A case study in a data-poor context in Sub-Saharan Africa illustrated the application of the approach, highlighting its strengths and shortcomings in supporting the design and assessment of watershed investments.

Chapter 5

Evaluating institutional capacity of water utilities

5.1 Introduction

This chapter focuses on the role of water utilities in the implementation of adaptive watershed management. It builds on the conceptual framework of the urban water sector, which highlighted their central role as institutions operating and maintaining the sector (Chapter 2). In Chapter 3, I showed empirical evidences of how, over a period of three decades, a water utility could implement adaptive watershed management, involving diverse stakeholders and knowledge systems. In Chapter 4, I analyzed an application of an operative approach that supports water utilities in designing watershed investments, to implement adaptive watershed management. Hence, as a way forward, this chapter explores the role of learning organization implementing adaptive management assuming that water utilities are "learning organizations" (Cowling et al., 2008).

Cowling et al. (2008) define a learning organization as an organization that is skilled at creating and acquiring knowledge and modifying its behavior to reflect new insights. They propose an operational model for implementing the safeguarding ecosystem services in real-life context. As shown in Figure 5.1, their model distinguishes between three stages of implementation that consider ecosystem services from different perspectives (biophysical and social), at different spatial scales (regional to local) and with different levels of stakeholder collaboration (informed, involved, empowered). The three stages lead to the identification of opportunities and constraints (Assessment), definition of strategies (Planning) and implementation of the safeguarding of ecosystem services through adaptive management (Management). The proponents of the model strongly argue the need for adaptive management to be institutionalized in a suit of learning organizations, each focusing on different ecosystem services. Ultimately, the operational model aims to achieving a socio-ecological systems that is resilient, i.e. can absorb shocks and surprises.

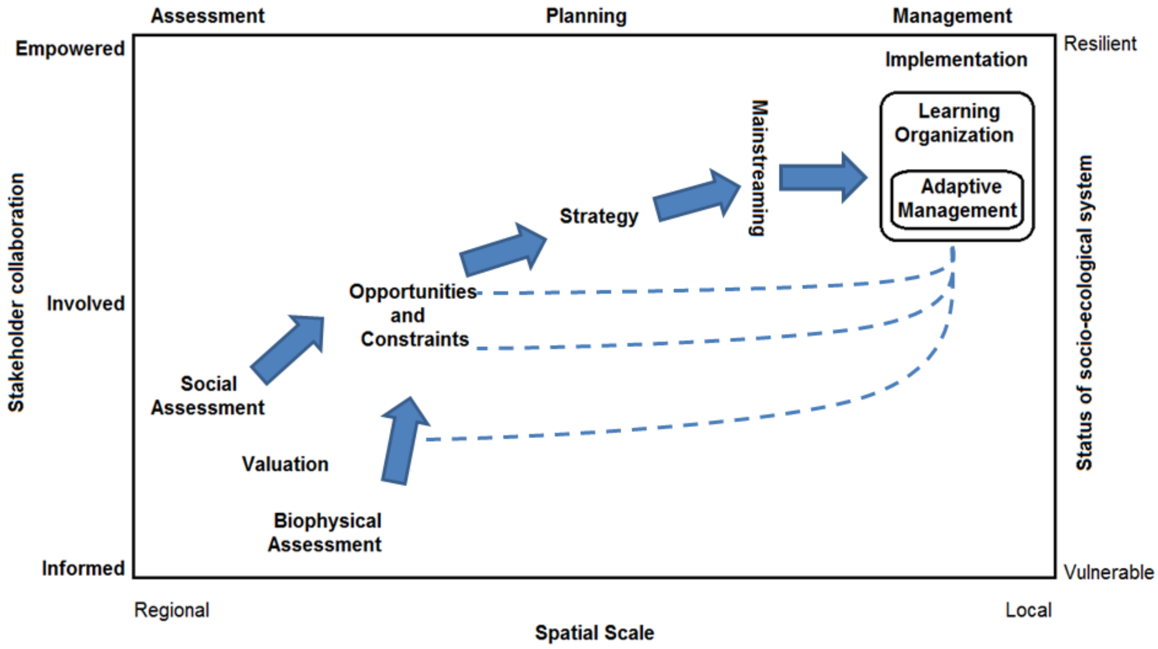


Figure 5.1: An operational model for implementing the safeguarding of ecosystem services. Achieving resilient socio-ecological systems, through a three-stage implementation strategy (Assessment, Planning and Management), each implying different spatial scales (regional to local), perspectives (biophysical and social) and degree of stakeholder involvement (Informed, Involved, and Empowered). Key role of learning organization implementing adaptive management (source: Cowling et al. 2008).

The idea of water utilities as learning organizations had already been explored by Kayaga et al. 2013. They developed a conceptual framework for evaluating the institutional capacity of water utilities, putting a strong emphasis on the concept of learning organization. In this chapter, I apply their framework to characterize the water utilities involved in the two case studies investigated in the previous two chapters. More specifically, to locate the Hannover Water Utility (HWU) and Asmara Water Supply Department (AWSD) along the spectrum of institutional capacity proposed by Kayaga et al (2013). Hence, use it to discuss the determinants of capacity that are the most significant for understanding the role of water utilities in implementing adaptive watershed management.

The remainder of the chapter is organized in four parts. Firstly, I introduce the conceptual framework proposed by Kayaga and colleagues for characterizing water utilities as learning organizations. Hence, I apply the framework to the case studies and I place the two water utilities along the spectrum of institutional capacity based on the results obtained in chapter

3, interview with a key informant and literature reviews. I propose a methodology of data collection to test my assumptions. Finally, I present some conclusion and way forward.

5.2 Water utilities as learning organizations

Recently, under the auspices of the World Bank, Kayaga and colleagues developed a conceptual framework for evaluating institutional capacity of water utilities: the so-called Water Utility Maturity Model (WUM) (Kayaga et al. 2013). The WUM has a sound theoretical basis, because it relies on an in-depth analysis of existing conceptualizations of institutions. At the same time, is oriented to real-life application; in fact, it built on a comparative analysis of numerous tools for evaluating institutional capacity (Cullivan et al. 1988, Baietti, Kingdom and van Ginneken 2006, Locussol and van Ginneken 2008, Suez Environment 2010, as cited in Kayaga), of the water sector (Saleth and Dinah 2004, AMCOW et al. 2006. AMCOW et al. 2011, Gandhi, Crase, Roy 2009, as cited in Kayaga) and of generic international development interventions (Lusthaus et al. 1995, DFID 2003, EU Commission 2009, Kimata 2008, as cited in kayaga). Interestingly, the WUM put emphasis on the concept of learning organizations. In fact, it defines institutional capacity as the capacity of organizations to “continuously generate a minimum level and quality of valued outputs, and to prioritize learning for continuous improvement” (Kayaga et al. 2013).

Underlying the definition is a conceptualization of institutions as “rules” and “roles” by which decision-making and implementation is structured. More specifically, institutions are conceptualized as a “combination of organizations, institutional mechanisms and institutional orientations” (Kayaga et al. 2013). Organizations are the most “tangible” class of institutions, which structure the choice of action of individual or corporate and other collective actors within a society. Mechanisms ad orientations are, respectively, the explicit or formal and the implicit or informal systems of rules that structure the choices of actions of individual or collective actors in a society. Therefore, water utilities are conceptualized as “organizational institutions (actors), which operate under, and are constrained by, the overall legal and institutional environment (rules)” (Kayaga et al. 2013).

Kayaga et al (2013) identified the five core capabilities that enable a water utility to “perform and survive in a turbulent operating environment”. This was done based on an approach proposed by “The European Centre for Development Policy Management”, which emphasizes the role of endogenous factors in determining the capacity of institutions, rather than external factors (e.g. foreign expertise). The five core capabilities are, namely, the capabilities to commit and engage; to carry out technical, service delivery and logistical tasks; to relate and attract resource and support; to adapt and self-renew; and to balance coherence and diversity (Kayaga et al. 2013). As shown in Figure 5.2, in the case of WUM, the five capacity dimensions were labeled as Behavior; Structure/processes; Capabilities; Organizational tools and Influence (Kayaga et al 2013). In the context of this chapter, what is the most important is that the five institutional capacity dimensions are "integrative, mutually exclusive and collectively exhaustive". Each capacity dimension has four to five attributes (23 attributes in total) that are characterized by five progressive levels of institutional capacity referred to as "maturity levels", namely: (1) Initial, (2) Basic, (3) Proactive, (4) Flexible and (5) Progressive. For an example, see Box 5.1 and Figure 5.3.

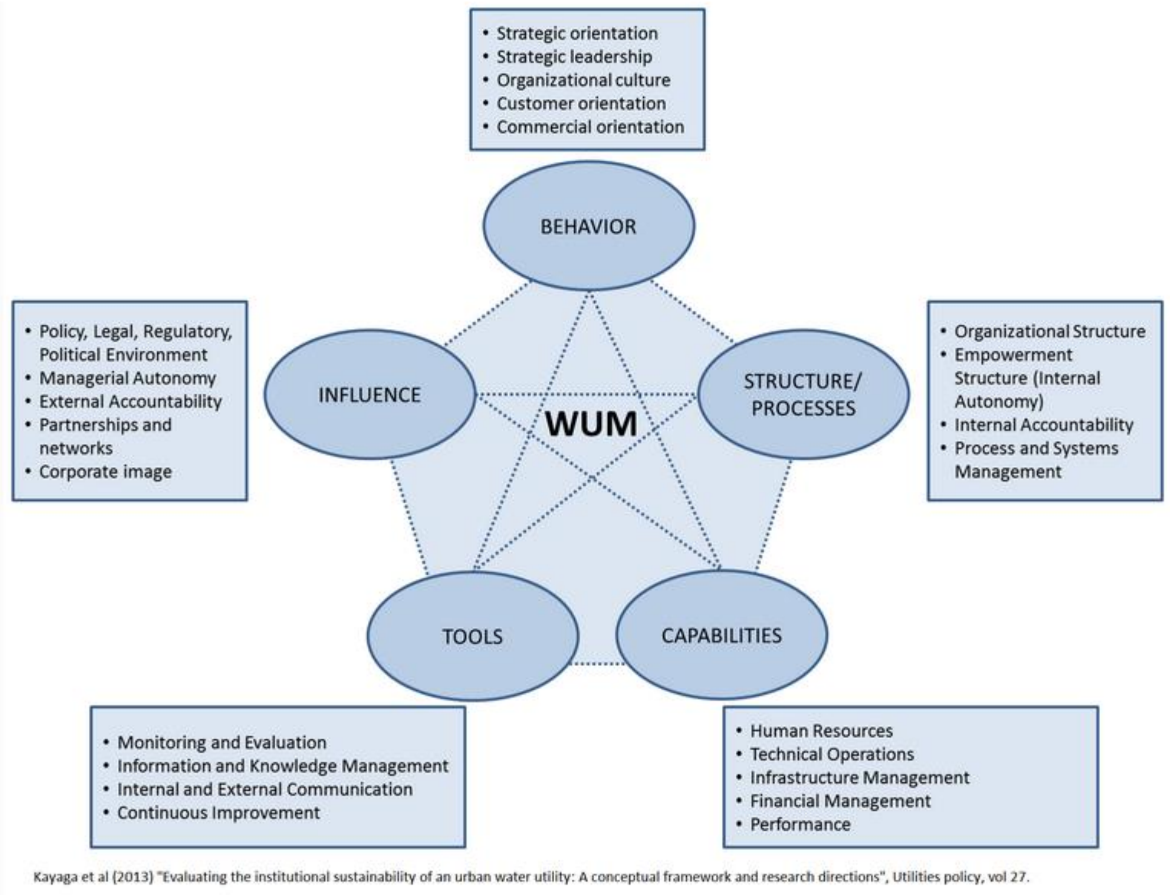


Figure 5.2: Water Utility Maturity Model a conceptual framework and related operative tools for evaluating institutional capacity of a water utility. (source: Kayaga et al. 2013)

Represented in Box 5.1 is the capacity dimension "Influence", which is indicative to the water utility's "ability to influence its operating environment in a positive and strategic manner" (Kayaga et al. 2013). This is perhaps the most significant capacity dimension to explore, within the scope of this chapter.

WUM – ATTRIBUTES OF CAPACITY DIMENSION “INFLUENCE”

Policy, Legal, Regulatory, and Political Environment

1) Leadership and staff not well conversant with factors in the external environment. Negative political influence is common.
2) Leadership passively interested in factors in the external environment, and reacts to them rather than strategically influencing them.
3) The external environment is actively monitored to develop understanding & reduce uncertainty.
4) Leadership continuously scanning the external environment, and adapting to changes through building organizational capacity for effective negotiation, and alignment of business processes, building networks and allies.
5) Utility has predictive capabilities, and carries out risk/opportunities assessment & and management; continuously adaptive to the external environment in near real-time.

Managerial autonomy

1) Utility managers lack autonomy to make important managerial and operational decisions.
2) There is limited managerial and operational autonomy.
3) Managers have more room to maneuver and innovate (i.e. have autonomy to effect internal managerial/operational changes to improve the effectiveness and productivity).
4) Utility has full autonomy with respect to most managerial, operational and financial decisions.
5) Utility has full autonomy with respect to all managerial, operational and financial decisions.

External accountability

1) There is no external accountability for performance.
2) External accountability mechanisms in place but not effective.
3) The utility is held accountable for performance by some of the external stakeholders.
4) Utility is held accountable for performance by some external stakeholders.
5) Utility has a balanced accountability framework.

Partnerships and networks

1) Partnerships and networks with outside organizations are not supported.
2) Partnerships and networks may be initiated by individual staff. Supplier communications are limited to tendering, order placement or problem resolution.
3) There is a policy that encourages and supports mutually beneficial partnerships and networking. Processes are in place to select, evaluate and rank suppliers.
4) There is a budge to develop and grow partnerships and networks. Relationship processes exist to develop key suppliers.
5) Partnerships are integrated within business processes.

Corporate image *

1) Corporate image is not recognized as an important service element and is not evaluated.
2) Leadership is aware of the importance of corporate image; however, it is not monitored or evaluated in a consistent and systematic manner.
3) Corporate image is periodically measured; but the results are not necessarily used for improvements.
4) Corporate image is continuously and systematically tracked. The results are widely made available inside the organization and used in the strategic planning process.
5) The results of the corporate image scans are integrated into the performance/incentive management system for staff.

Box 5.1: Five attributes of the institutional capacity dimension “Influence” and respective five progressive maturity levels (source: Kayaga et al. 2013).

Figure 5.3 shows the labelled progressive levels of maturity of the attribute “partnership and networks” of the capacity dimension “influence”. It was selected because of its relevance for the scope of this chapter. In Figure 5.3, worth of notice is how “learning” takes place overtime (x-axis); this is indicative of how the WUM can be both a diagnostic and benchmarking tool. It can be used to identify both barriers to progressing between maturity levels and potential enablers to overcome such barriers.

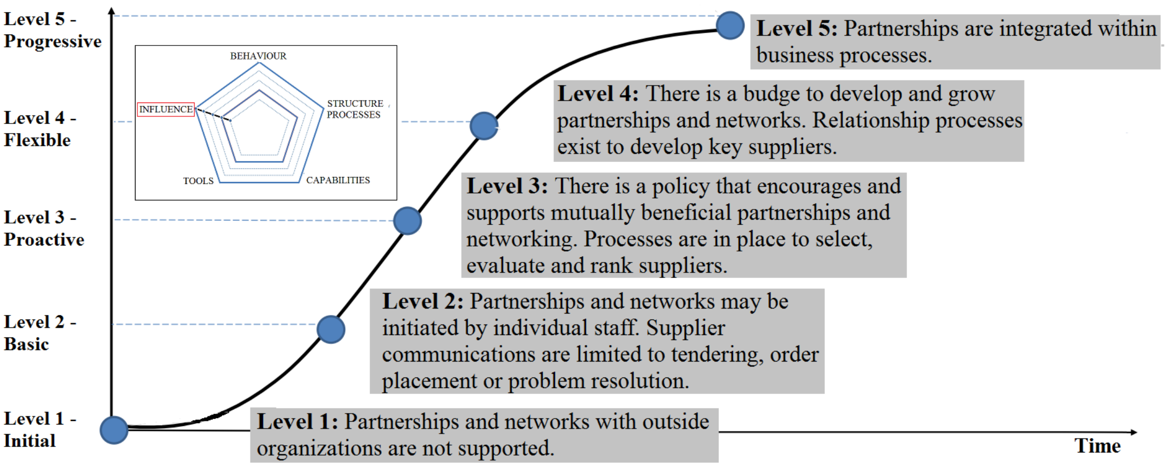


Figure 5.3: Example of labelled progressive maturity levels for the attribute “Partnership and networks” of the capacity dimension “Influence” (source: Kayaga et al. 2013)

5.3 Methods

The methodology consists of two parts. In the first part, the WUM is applied to locate the HWU and AWSD along the spectrum of institutional capacity proposed by the Kayaga et al (2013). This is done based on previous investigations in chapter 3 and 4 (HWU and AWSD, respectively) as well as interviews with key informants and literature review (AWSD). Hence, focusing on the capacity dimension “Influence”, the collected information is used to gain a good understanding of the role that the water utilities could play in the implementation of adaptive watershed management.

In the second part, primary data is collected through two questionnaires (in English and German), based on the WUM. Respondents are asked to select from the labelled progressive levels of the WUM the maturity level that best described their water utility. Hence, for each capacity dimension, to rank the attributes based on their importance for the specific water utility. Finally, to rank the five capacity dimensions against each other. For both HWU and

AWSD, the questionnaires will involve three senior managers and an informed scientist. Once, collected the primary data will be used possibly to test the WUM.

5.4 Preliminary results

Hereby I present some preliminary results, and discuss some assumptions. Table 5.1 compares the main characteristics of HWU and AWSD, based on documentary sources (Enercity 2011a, 2011b, Zeraebruk et al. 2014).

Table 5.1: Comparing the main characteristics of Hannover Water Utility and Asmara Water Supply Department (source: Enercity 2011a, b and Zeraebruk et al. 2014).

	HWU	AWSD
Water resources	Groundwater extracted from 106 wells, of which 90 are located in the Fuhrberg watershed to the north of Hannover, and 16 in Grasdorf, a much smaller watershed to the south of Hannover	Surface water collected as runoff during two wet seasons (Kiremti and Asmera), stored mainly in 4 reservoirs. The Toker, Adi-Sheka and Mai-Sirwa reservoirs are located, to the north of Asmara. The Mai Nefhi dam is located southwest of Asmara, in a sub watershed of the Barka River
Governance mode	Joint stock company owned almost entirely by the city of Hannover	Public utility managing water and sanitation services in the Eritrean capital city Asmara
Served population	650 thousand people in Hannover and surrounding districts	350 thousand out of the target population of 450 thousand in Asmara & surrounding districts
Coverage of population	100%	77%
Number of connections	90,000	34,128
Yearly delivered water	40 million cubic meters	7,46 million cubic meters
Number of employees	70 (0.8 every 1000)	460 (13.48 every 1000)
Average working age	19 years	-
Annual sales revenue	Euro 70 million	US$ 4.85 million
Number of waterworks	Three: Fuhrberg, Elze-Berkhof and Grasdorf	Three: Stretta Vaudetto, Adinfas and Mainefhi
Daily production capacity	-	44,000 cubic meters per day, often reduced to half due to technical problems, aging infrastructure and at times to limited volume of water in storage reservoirs
Length of feeder, mains and distribution pipes	2,200 Km	-
Length of house connections	1,200 Km	-

Noteworthy are the differences in terms of the annual amount of water delivered (40 versus

7.46 million cubic meters), the number of employee every 1000 connections (0.8 versus 13.48), and the water sources (groundwater versus surface water).

Figure 5.4 is a preliminary result. It represents the assumptions made concerning the institutional capacity of HWU (green) and AWSD (red). For HWU, the assumptions was based on the results described in Chapter 3 and the review of reports by HWU (Enercity 2011a, 2011b). For AWSD, the assumption was supported by an interview with a senior manager and the results of a detailed assessment of the water supply services and operational performance of AWSD described in Zeraebruk et al. (2014). As shown in Figure 5.4, it was assumed that the HWU is a Level 5 – water utility with Progressive maturity, while the AWSD is a Level 2- water utility with Basic maturity. The assigned level refers to all the 23 attributes of the five capacity dimensions of the WUM.

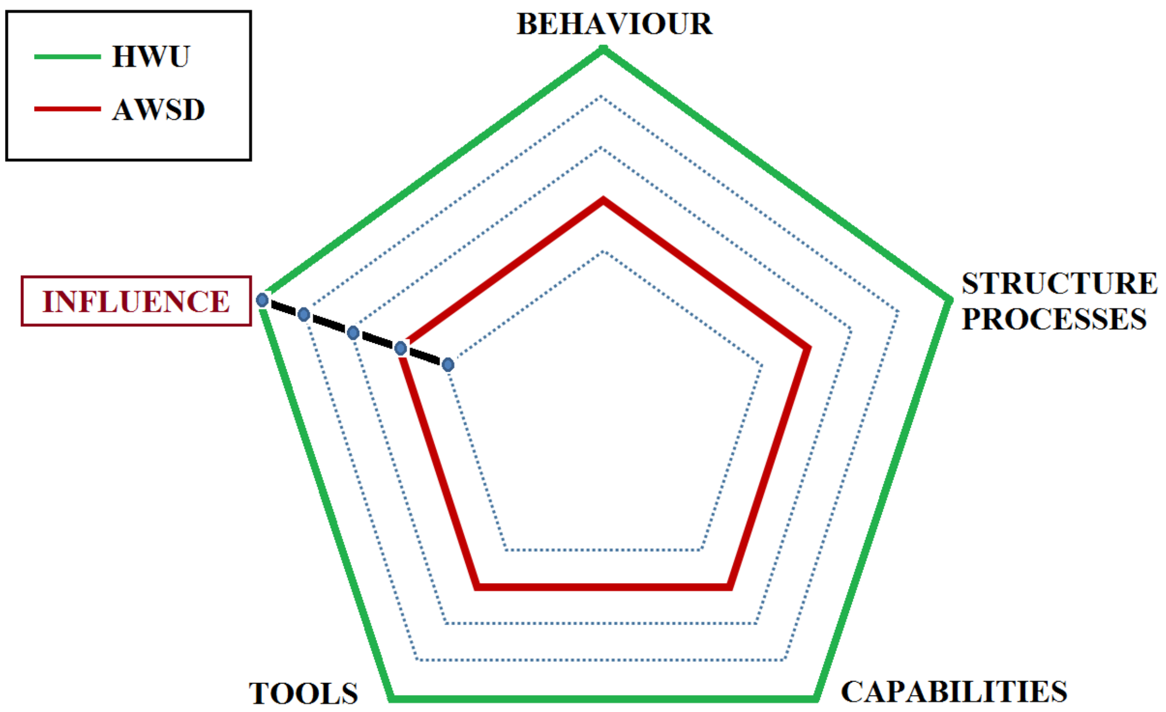


Figure 5.4: Assumptions on institutional capacity of Hannover Water Utility and Asmara Water Supply Department. Highlight of the capacity dimension "Influence" as the most significant for implementation of adaptive watershed management.

In Figure 5.4, noteworthy is the focus on the capacity dimension "Influence", which was assumed as the most significant for understanding the role of a water utility in implementing adaptive watershed management. Moreover, the focus on a single capacity dimensions is justified by the fact that the dimensions of the WUM were "integrative, mutually exclusive and collectively exhaustive”. Therefore, Table 5.2 provides a reasonable comparison of HWU and AWSD with respect to the five attributes of the capacity dimension “Influence”.

Table 5.2: Comparing Hannover Water Utility and Asmara Water Supply Department under five attributes of the capacity dimension “Influence”, the most significant for implementation of adaptive watershed management.

Attribute	HWU	AWSD
Policy, legal, regulatory, and political environment	Utility has predictive capabilities, and carries out risk/opportunities assessment and management; continuously adaptive to the external environment in near real-time.	Leadership passively interested in factors in the external environment, and reacts to them rather than strategically influencing them.
Managerial autonomy	Utility has full autonomy with respect to all managerial, operational and financial decisions.	There is limited managerial and operational autonomy.
External accountability	Utility has a balanced accountability framework.	External accountability mechanisms in place but not effective.
Partnerships and networks	Partnerships are integrated within business processes.	Partnerships and networks may be initiated by individual staff. Supplier communications are limited to tendering, order placement or problem resolution.
Corporate image	The results of the corporate image scans are integrated into the performance/incentive management system for staff.	Leadership is aware of the importance of corporate image; however, it is not monitored or evaluated in a consistent & systematic manner.

5.5 Some conclusions and the way forward

This chapter aimed at gaining a good understanding of the role of water utilities in the urban water sector. More specifically, of their role as learning organization implementing adaptive watershed management for ecosystem services, as suggested by Cowling et al. (2008). To this end, evaluating institutional capacity of a water utility, I used the WUM model, a promising tool with a solid theoretical basis and strong orientation towards real-life application. I applied it to the water utilities involved in the two previously investigated case studies: the HWU and AWSD.

I reviewed the general characteristics of the two water utilities. Then, the available information from documents, literature and the results obtained in Chapter 3, together with an interview with a key informant allowed me to apply the WUM framework to the water utilities of Hannover and Asmara.

The results show that their institutional capacity is Level 5 – Progressive water utility (HWU) and Level 2 – Basic water utility (AWSD). I propose a methodological empirical pathway to test my results. In any case, from these preliminary analysis I can say that the results highlighted the potential of the WUM to provide a detailed characterization of water utilities and their institutional capacity. In particular, their ability to become a central actor in the in the implementation of an adaptive watershed management for ecosystem services.

Chapter 6

Conclusions

The main goal of this research was to develop and test operative approaches to support the implementation of adaptive management of watersheds, considering water utilities as central actors. The work was driven by four specific objectives:

- ❖ Building a conceptual framework of the urban water sector form an ecosystem services perspective.
- ❖ Empirically exploring boundary work in adaptive watershed management for ecosystem services, promoted by a water utility.
- ❖ Building and testing an approach for designing and assessing the impact of watershed investments, to implement of adaptive watershed management.
- ❖ Exploring water utilities as learning organization implementing adaptive watershed management.

In this chapter, the main findings of the research grouped by the four specific objectives are discussed and some recommendations are discussed for future research.

6.1 The urban water sector and ecosystem services: a conceptual framework

Implementing adaptive watershed management is a complex issue. Thus, a simple and flexible conceptual framework of the urban water sector, from an ecosystem service perspective was built. It provided an overview of the main challenges and trends that characterize the sector, thus set the background for further analysis.

This part of the research aimed to gain an overview of the urban water sector and the complexities it entails. Thus, it built a simple and flexible conceptual framework of the urban water sector from an ecosystem service perspective, based on an original review of the literature. The proposed framework attempted to synthesize the most relevant aspects characterizing the exchange of water between watersheds and cities, and within the city. It highlighted the role of urban water infrastructures in (i) linking ecosystem services production and benefit areas, (ii) in bridging spatial scales ranging from the watershed to the household level and (iii) in adopting ecosystem services-based responses to water vulnerability. Noteworthy is it built on internationally accepted frameworks (e.g. SEEA-Water) and concepts (e.g. Integrated Urban Water Management) and, at the same time, it took the ease of application into account (e.g., use of layperson terms). In fact, the framework attempted to be as simple, intuitive and flexible as possible therefore it has a good potential to be used as a tool for involving stakeholders. Finally, an illustrative application as a tool for reviewing real-life infrastructural projects showed the potential and the limits of the framework.

Attempting to represent a whole "management paradigm" (Pahl-Wostl 2011), the findings of this part of the research and the proposed framework are arguable, not exhaustive and provide an overall idea of the urban water sector. Nevertheless, despite these limitations, the proposed framework can be a useful starting point for seeking a better understanding of the complex relationship between long-term human wellbeing in cities and the respective service providing and life-supporting watersheds.

6.2 Boundary work in adaptive watershed management

Linking diverse sets of stakeholders and knowledge systems is a key challenge. Boundary work promotes an active management of the tension arising at the interface between stakeholders with different perception of relevant knowledge. Therefore, empirical evidence of boundary work was analyzed to assess its applicability to the implementation of adaptive watershed management.

The framework of boundary work by Clark et al. (2011) proved very useful for understanding facilitation of knowledge transfer in adaptive watershed management for ecosystem services, promoted by a water utility. The framework provided guidance on how to address successfully the linkage of a set of diverse stakeholders and knowledge systems, across management levels, and across sector (Kowalski and Jenkins 2015). It highlights the importance of defining the context in terms of "what (?) Knowledge is being used for", and "how users perceive the source", to thus identify possible barriers, relevant criteria and most appropriate boundary work strategies.

For the case study, five most illustrative boundaries were investigated. They represented different stakeholders and knowledge systems (scientists, water managers, farmers and landscape planners) and types of tension (“basic versus applied research”, “disciplinary versus interdisciplinary”, “long-term versus real-time”, and “autonomy versus consultancy”) (Parker and Corona, 2012). Accordingly, the main barriers to knowledge transfer were identified, hence, the actual boundary work put in place to overcome them assessed against the theoretical potential of interaction (Clark et al. 2011). The empirical results suggest that scientific insights have been crucial for "enlightenment", "decision-support", and in "negotiations" between a water utility and stakeholders in Fuhrberg watershed management. With respect to "enlightenment" and "decision-support", effective interaction among knowledge users and producers has been timely achieved, resulting among other things in peer-reviewed publications, the utility's decision to buy more than 20,000 ha of land, or to covert coniferous to deciduous forests to protect groundwater. We attribute these successes to boundary work activities deployed by the water utility and ultimately its high institutional capacity. For decisions and negotiations with other stakeholders, knowledge transfer has emerged from the outcomes of prior boundary work in combination with a stepping up of cooperation between relevant actors and a supportive socio-ecological context in the form of ongoing social learning.

Moreover, the analysis confirmed that boundary work is not a single time achievement, rather a dynamic process that has to address a diverse set of “tensions” (Parker and Corona, 2012). Therefore, the utmost importance of considering the embedding socio-ecological context. In particular, having a deep understanding of the contextual and contingent factors and relative influence of social actors is a prerequisite for any boundary work. Furthermore, in the chapter it was argued that the distinction between the nine combinations of knowledge use and source proposed in Clark et al 2011 (Figure 3.1), should not be drastic; rather there should be gradual transition from on context to its neighboring ones.

This chapter provided one of the first empirical assessments of boundary work in practice and presented many promising approaches for initiating and facilitating boundary work in the case of water utilities. The approaches for boundary work identified in the case study can be replicated in other water utilities – at least in cases with a similar governance context. Finally, the four-step methodology, going from an overall understanding of the socio-ecological context to an inquiry with high empirical resolution level, can indicate a useful pathway for understanding and promoting boundary work in watershed management for ecosystem services.

The main weakness of this part of the study deals with the fact that it considered a single case study, therefore, the limited degree of generalizability of its findings. The Fuhrberg watershed was selected because it is informative concerning boundary work in practice. The actors in the Fuhrberg case study can be seen as frontrunners in such efforts of boundary work that have been built upon several decades of experiences in transdisciplinary research, testing, and development. At the same time, the Fuhrberg case study is comparable to several other watersheds in Germany, Europe, and beyond, where similar efforts to establish cooperation between water utilities and land users have been put in place. Examples of this are found in the German cities of Leipzig and Munich, and in the Catskills-Delaware watershed in New York, USA. The approaches for boundary work identified in the case study can be replicated in other water utilities – at least in cases with a similar governance context. Therefore, the approaches for boundary work identified in the case study can be replicated in other water utilities – at least in cases with a similar governance context. To this end, more comparative research is required to understand better the influence of contextual differences on appropriate methods and potential outcomes of boundary work, and to provide generalizable conclusions and guidelines for boundary work for water utilities and environmental resource planning and management.

6.3 Designing and assessing watershed investments

If properly designed, watershed investment can become important financial and governance mechanism to promote the implementation of adaptive watershed management.

In chapter 4, an operative approach for designing and assessing impact of watershed investments was built and applied. The proposed process-based approach builds on spatially explicit modeling of ecosystem services and insights on boundary work. It is structured to facilitate negotiations among stakeholders: distinguishing between a Strategic Component addressing concerns of saliency and legitimacy and a Technical Component ensuring credibility, respectively. The former includes setting the agenda, defining investment scenarios, and assessing the performance of watershed investments. The latter, concerns data processing and preparation, tailoring spatially explicit ecosystem service models, hence applying them to design a set of “investment portfolios”, generate future land use scenarios, and model impacts on selected ecosystem services. A case study involving a medium-sized city and its watershed, in a data-scarce context in Sub-Sharan Africa was selected: Asmara city and The Toker watershed in Eritrea. Soil erosion and water scarcity-related challenges were associated to two illustrative watershed investment objectives: urban water security and rural poverty alleviation. The case study application produced spatially explicit data (investment portfolio, land use scenario, impact on ecosystem services), which was aggregated to quantitatively assess the performance of watershed investments, in terms of changes in a selected ecosystem service; thus answering key management and planning questions.

The proposed approach, by addressing stakeholders' concerns of credibility, saliency, and legitimacy, is expected to facilitate negotiation of objectives, definition of scenarios, and assessment of alternative watershed investments. Ultimately, it can contribute to implementing adaptive watershed management, by supporting the design of watershed investments. In fact, watershed investments are considered a promising opportunity for achieving large-scale transitions towards sustainability, in the near future.

Beyond the single case study issue, the main weakness of this part of the research is the limited involvement of actual stakeholders on the case study, which lead to different assumptions concerning, for example, the selection of illustrative investment objectives, reclassification of land use and the unit cost of activities. Another limit was the coarse resolution of some of the data used for the modeling (e.g. rainfall erosivity), and the models were not calibrated. Finally, the focus on a single ecosystem service, i.e. soil erosion control, seems to be at odd with the holistic approach of the ecosystem service approach. Therefore, the results are only illustrative of the potential application. In part, the limited degree of generalizability was addressed by focusing on medium sized cities in the Global South and two common socioecological challenges affecting such cities: soil erosion and water scarcity. In fact, the case study application highlighted the main challenges in terms of data paucity as well as boundary work that should be put in place to facilitate the negotiation among stakeholders. In particular, building on real-life experiences and tools developed by the Water Funds, mainly in Latin America, it showed a possible operationalization of the ecosystem services approach for watershed management in data-poor contexts in Africa. Further research, involving actual stakeholders in the case study would allow to test the here proposed operative approach.

6.4 Exploring water utilities as learning organization

As "gate-keepers" for the introduction of any novelty in the urban water sector, it is important to have a good understanding of water utilities as institutions assessing the extent to which they are skilled at creating and acquiring knowledge and modifying their behavior to reflect new insights.

In this chapter, a tool for exploring water utilities as learning organizations implementing adaptive watershed management was identified and applied to the two case studies of this research. The Water Utility Maturity Model developed by Kayaga et al. (2013) has both a strong theoretical basis and orientations towards real-life application. Its application to the two water utilities, the Hannover Water Utility (Germany) and Asmara Water Supply Department (Eritrea), allowed identifying the institutional capacity dimensions that most affect a utilities ability to influence its operating environment. The capacity dimension "Influence" and its five attributes were assumed as the most important for gaining a good understanding of the role of a water utility in implementing adaptive watershed management. The two water utilities were evaluated as Level 5 – Progressive water utility and Level 2 – Basic water utility, respectively. However, this preliminary result needs to be confirmed collecting primary data from both case studies.

A weakness of this chapter is its reliance on the Water Utility Maturity Model. In fact, it took for granted the five capacity dimensions were actually integrative, mutually exclusive and collectively exhaustive as argued by Kayaga et al. (2013). Indeed, the tool is new and so far had only been piloted by two water utilities in South Asia (Kayaga et al. 2013). Therefore, once collected, the primary data from the two case studies in two different contexts, could contribute to testing the promising tool proposed by Kayaga et al. (2013).

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Appendices

Appendix 1 contains a review of three illustrative papers mentioned in Chapter 2. They addressed the challenges of the urban water sector from at least three different perspectives that can be summarized as role of social actors, role of water utilities, and a global perspective.

Appendix 2 contains an interview protocol used for the empirical investigation of boundary work the Fuhrberg watershed management in Chapter 3 (Questionnaire B in Table 3.4).

Appendix 3 synthesizes the RIOS approach described in Chapter 4, based on Vogl et al. (2015). It shows the three modules of RIOS (Investment Portfolio Advisor, Portfolio Translator and Benefit Estimator), including a flow diagram of the main analysis carried out in the RIOS Investment Portfolio Advisor.

Appendix 1

Challenges of the urban water sector

The challenges of the urban water sector and the water sector in general have been addressed from at least three different perspectives that can be summarized as role of social actors, role of water utilities, and a global perspective.

Role of social actors

The role of social actors, as explored by Domènech et al. (2013) is fundamental to understand the future of the urban water sector. It is evident the looming risk of water scarcity, associated to a "growth-at-any-cost" paradigm compounded by effects of climate change and the necessary change of paradigm from currently employed supply-side water strategies (e.g., construction of large infrastructures and water transfers schemes) to demand-side water management strategies (e.g. use economic tools such as water pricing, and ecological modernization). Domènech et al. (2013) using the Metropolitan Area of Barcelona as a case study, investigate the role of local adaptation strategies and social actors in promoting ecological modernization, by comparing the real or perceived socio-environmental performance (Munda 2007) of four non-conventional water sources: desalinated water, reclaimed water, greywater, and rainwater. Among other things, the paper identified existing mismatches between stated preferences of stakeholders and actual policy practices, alliances and conflicts between social actors, as well as windows of opportunities for promoting ecological modernization.

Role of water utilities

Lieberherr and Truffer (2015) explores the role of water utilities among others. This paper focuses on the role of water utilities as central institutions in the urban water sector. It investigates three water utilities embedded in three different governance modes (public, private, and mixed), attempting to understand how the latter affects the introduction of novelty in the urban water sector, including more decentralized solutions. In particular, the paper introduces the concept of "dynamic capability" of water utilities, which put simply is the utility's capacity to innovate and adapt, also drawing from its wider network of partners (Lieberherr and Truffer 2015). Based on their analysis, water utilities in private and mixed governance modes tend to perform better in terms of degree of innovativeness, but less in terms of long-term sustainability criteria. Therefore, the authors could not reach a clear conclusion on the impact of privatization on sustainability transitions; in fact, there are several multi-dimensional trade-offs between static and dynamic sustainability criteria.

A Global perspective

Srinivasan et al. (2012) have explored the global perspective of the global water crisis and its causes. Based on a meta-analysis of 22 case studies of coupled social-ecological systems, worldwide, these authors identify different outcomes of water resource systems as well as the factors that drive them. Accordingly, they define six types of "syndromes" affecting the water sector, namely: groundwater depletion, ecological destruction, drought-driven conflicts, unmet subsistence needs, resource capture by elite, and water reallocation to nature. According to the authors, all syndromes can be explained by a limited set of causal factors that can be grouped into four categories, namely: demand changes, supply changes, governance systems, and infrastructure/technology. Therefore, identifying which syndrome class a watershed belongs to, and tracing common causal pathways, can help design better policies to achieve sustainability goals.

Appendix 2

Interview protocol for boundary work investigation

<table>
<tr><th colspan="2">QUESTIONNAIRE B</th></tr>
<tr><td>INTRODUCTION
(5 minutes)</td><td>Thank you for agreeing to meet with us. I am BLAL ADEM a PhD Student from the University of Trento (Italy), and a visiting researcher at the IUP in Leibniz University of Hannover (LUH). I also have with me my colleagues Dr Christian Albert and Mr. Dennis Tietz both from the IUP in Leibniz University of Hannover (LUH).

The focus of this research is the "use of scientific knowledge in decision making" by the Hannover Public Utility in the Fuhrberg watershed. We are speaking with experts and stakeholders in order to get a better understanding of "how scientific knowledge was used or not used in decision-making and implementation, and the degree of involvement of the stakeholders".

Starting from the late 70s the utility have been involved in research projects dealing with groundwater quality and its determinants. The research outcomes were crucial for decisions taken by the utility, including acquisition of land, launching of extension services, and signing of voluntary agreements with farmers. This study is trying to shed light on the mechanisms that made translation of scientific knowledge into concrete measures on the ground possible. The University of Trento funds this study.
As expert who are directly involved in developing and implementing a groundwater-friendly watershed management system in the Fuhrberg area, we would like to discuss with you about the implementation of such a system.

What we learn from today’s discussion will help us identify challenges, and strategies that water utilities can adopt to translate scientific knowledge into action.

We will treat your answers as confidential. We will not include your names or any other information that could identify you in any reports we write.

Do you have any questions about the study?</td></tr>
<tr><td>TOPIC 1
(10-15 min.)</td><td>TOPIC #1: INTRODUCTION - THE WATER DIVISION

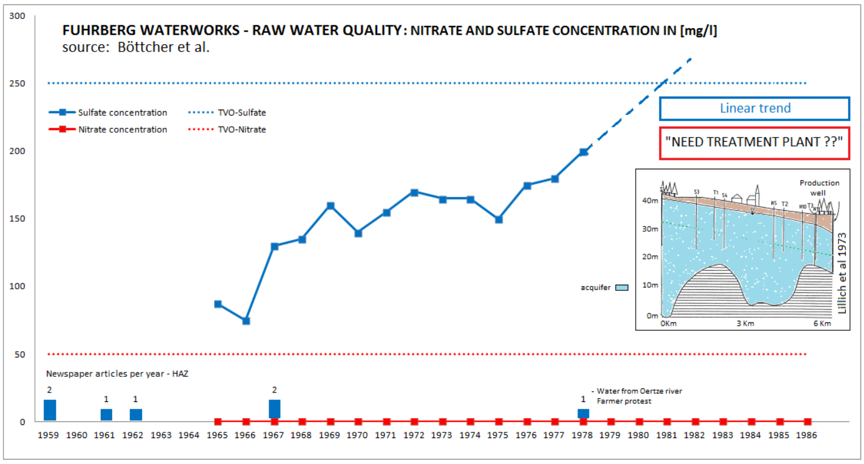
1. A. To begin, can you briefly describe the Water Division of the Hannover Public Utility - HPU? What are its broad responsibilities? How is it embedded within the overall structure of the HPU? Which other organization outside the HPU does it interact with?
Broad responsibilities of the Water Division;
Description of the functional differentiation within the Water Division, and the deployment of staff over the different functions;
Interaction with other divisions of the HPU;
Interaction with other organizations outside the HPU;
NB. To help us follow better we will make a graphical representation, please feel free to add or correct something. At the end, make a brief summary of the organizational structure!

1. b. (IF THERE IS EXTRA TIME!) Now tell us more about the type of decisions that the Water Division can take autonomously, and the ones that require authorization from other entities. Can you tell at what level are the following decisions taken? (see table 1)</td></tr>
</table>

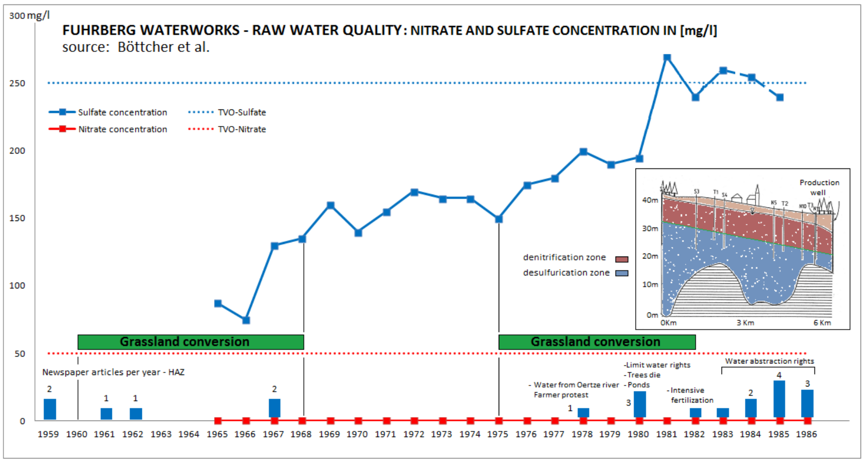
TOPIC 2
(15-20 min.)

TOPIC #2: DECISION MAKING - WATER TREATMENT PLANT (S1-U1 OR S1-Um)

2. Let's now talk about the HPU's experience in the Fuhrberg area, from the late 50s until the late 70s, shortly before the raw water quality concerns arose. How would you describe it? What was the relationship of the HPU with the farmers and authorities in the Fuhrberg? Besides the farmers and local authorities, were there other stakeholders?



3. In the late 70s, the HUP faced problems dealing with the raw water quality from the Fuhrberg. It was estimated in few years the concentration of sulfates in the raw water could reach the threshold value of 250 mg/l (see Figure 1). How did the HUP react? What did it concretely do to face the problem? Who got involved and how?



4. Let's now talk about the role of the director of waterworks laboratories, Dr. Walter Kölle. How would you describe his role concerning the water quality problems in the Fuhrberg? For e.g. what was his mandate when taking part in joint-research projects in partnership with a Federal research institute? Can you tell us something about him:

- What role did he play in decisions related to the raw water quality issues

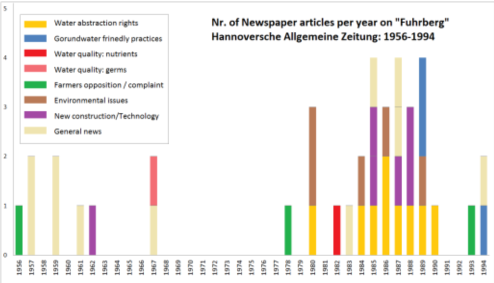
5. In the early 80s, the HPU had to decide whether to install a new treatment plant due to the high sulfate concentration. Finally, the HPU accepted the hypothesis of the scientists that concentration of sulfates in the raw water would decline within 3-4 years. How did this happen? How was the uncertainty of the scientific finding dealt with? What other alternative solutions did the HUP take into account?

6. The research carried out in the Fuhrberg, led by Dr Kölle and Dr Strebel, contributed significantly to the understanding of the biophysical process that determine the groundwater quality. Yet, not all the scientific findings have been used as a basis for decision and action by the HUP. Who is responsible for discriminating between knowledge to be used or not, and how?

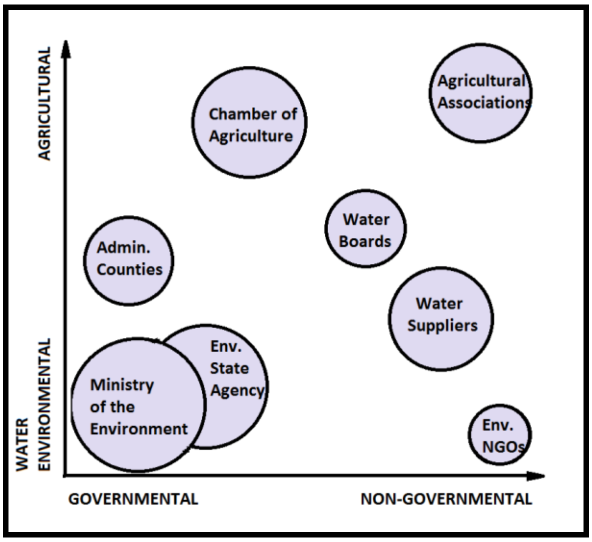
TOPIC 3 (15-20 min.)	**TOPIC #3: NEGOTIATION -BUY LAND & COOPERATION WITH FARMERS (Sm-Um)**

HAZ 04/09/1982) "Intensive Düngung gefährdet Wasser im Fuhrberg Feld. Stadtwerke warnen vor zunehmenden Sulfatkonzentrationen.
HAZ 02/03/1989 "Wegen des Wassers: Stadtwerke wollen Großgrundbesitzer werden. Gelände von 15fachen große der Eilenriede als Schutzflache bei Fuhrberg?"
HAZ 03/03/1989 *"Grune: Oko-Landbau im "Fuhrberger Feld"*

7. These are some newspaper articles from the HAZ, which cover almost one decade of history dealing with raw water quality in the Fuhrberg area. Put simplistically, the story starts with the deterioration of the raw water quality in the early 80s, and concludes in the late 80s with: (i) acquisition of land by the HUP, and (ii) signing of voluntary agreements with farmers in the Fuhrberg. Can you tell us something about the process that lead to these two decisions? What was the specific role-played by the utility?



- What were the main stages of the process?
- Who was involved in the process, and at which stage and with which role?
  - Farmers: when, how and to what extent were they involved?
  - Scientific community - Planners
  - Costumers
  - Authorities
  - Public - NGOs
- Can you make a list of the actors that were involved in addressing this specific issue - both organizations and individuals?
- Can you arrange the actors according to their main interest (from "*water/Environment*" to "*agriculture*") and their "*governmental*" or "*non-governmental*" nature? (We need a paper with the diagram, and actors)
- Can you assign a weight from 1 to 5 to the respective influence of each actor (**5** very influential, **1** less influential).
- What do you think about the diagram proposed by Kastens and Newig (2007)



TOPIC 4 (20-25 min.)

TOPIC #4: SCALING UP OR REPLICATION OF THE FUHRBERG EXPERIENCE

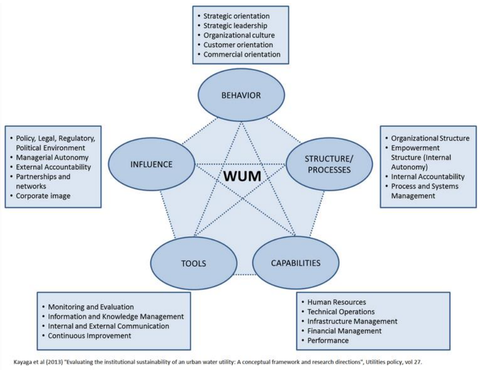
8. The last thing that we would like to discuss deals with the extent to which the HUP's experience in the Fuhrberg area can be **scaled up** and/or **replicated** somewhere else. To this end, it's worth recalling two aspects that were crucial for the success of the Fuhrberg experience: firstly, the **HUP bought almost all the land within the Zone 2 protected area** (50 days residence time), secondly the **State of Lower Saxony provided the financial coverage** of the voluntary agreements with the 190 farms covering 13.000 ha out of the 30.000 in the Protection area.
Now imagine you had to introduce a watershed management system similar to the one in Fuhrberg, somewhere else. For instance, let us think about the Hase subbasin. As a water utility, how would you proceed?

- What do you think maybe the main challenges?
- Who could be the main stakeholders, and how to engage them?
- Where to get the resources to cover the whole operation?
- What could be the role of a water utility?
- What is the role of the HUP costumers, and the society in general?

TOPIC 5 (15-20 min.)

TOPIC #5: INSTITUTIONAL CAPACITY - RANKING OF CAPACITY ATTRIBUTES

9. The last topic deals with a tool for assessing the INSTITUTIONAL CAPACITY of a water utility, i.e. its capacity to pursue its mission. Put simplistically, the mission of a water utility is to provide safe and affordable water to users, in a financially viable way, and with due care of the environment.
Tapping on your experience as water managers, we would like learn more about the determinants of institutional capacity of a water utility.
There are many tools and guidelines for evaluating the institutional capacity of a water utility. Today, with your assistance we would like to investigate one, the Water Utility Maturity model. The WUM identifies 5 broad dimensions of institutional capacity. Each capacity dimension is characterized by 4/5 attributes.



Kayaga et al (2013) "Evaluating the institutional sustainability of an urban water utility: A conceptual framework and research directions", Utilities policy, vol 27.

First, we would like you to read the attributes within each capacity dimension, and based on your experience at the HUP rank them from 1 to 4/5. 1 is the most important attribute. Subsequently, assign a weight from 0 to 100 to each capacity dimension. The weight expresses how much in percentage each capacity dimension contributes to the overall institutional capacity of the utility.

COMMENTS (5 minutes)

FINAL COMMENTS

Those were all of the questions that we wanted to ask.
10. Do you have any final thoughts about the Hannover water utility experience in Fuhrberg area that you would like to share?
Thank you for your time

TOOLS FOR THE INTERVIEW

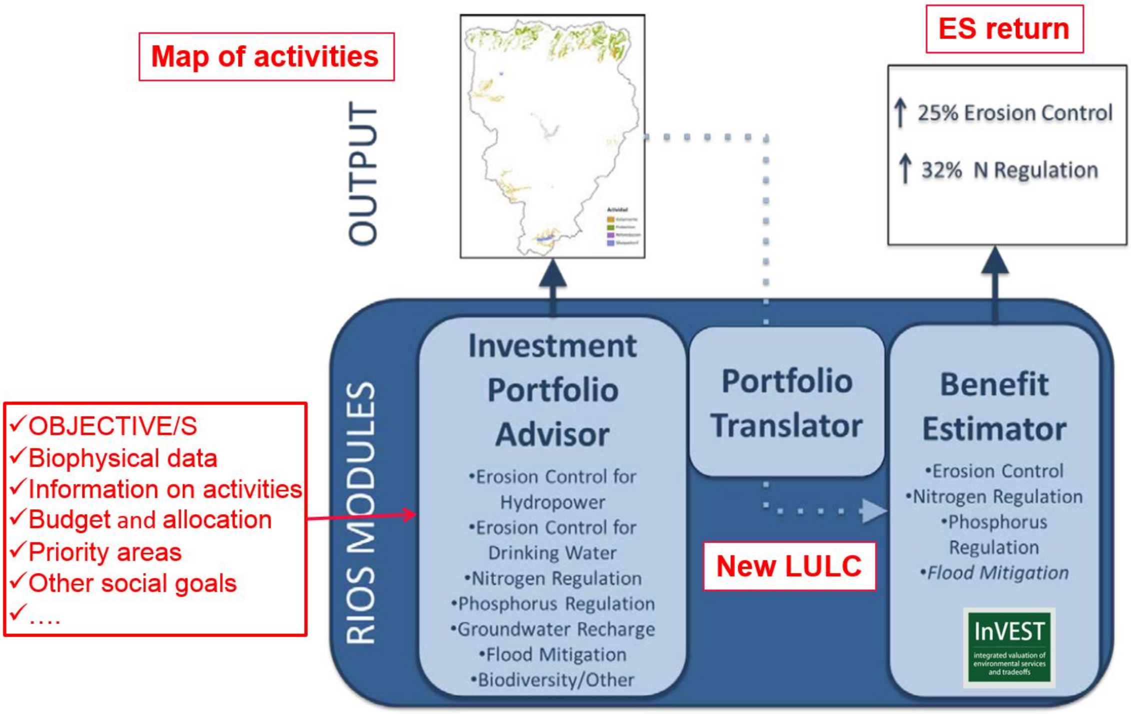
- Table 1: decentralization of decision making - A4
- Graph showing the sulfate concentration - different versions
- List of news: paper articles
- A2/A1 Paper for drawing relative position of actors
- A3 diagram: relative position of actors Kastens & Newig, (2007)
- A2/A1: Water Utility Maturity Model (Kayaga et al. 2013).

Appendix 3

"Investment Portfolio Advisor" – Flow diagram

The information is this appendix is based on Vogl et al. (2015).

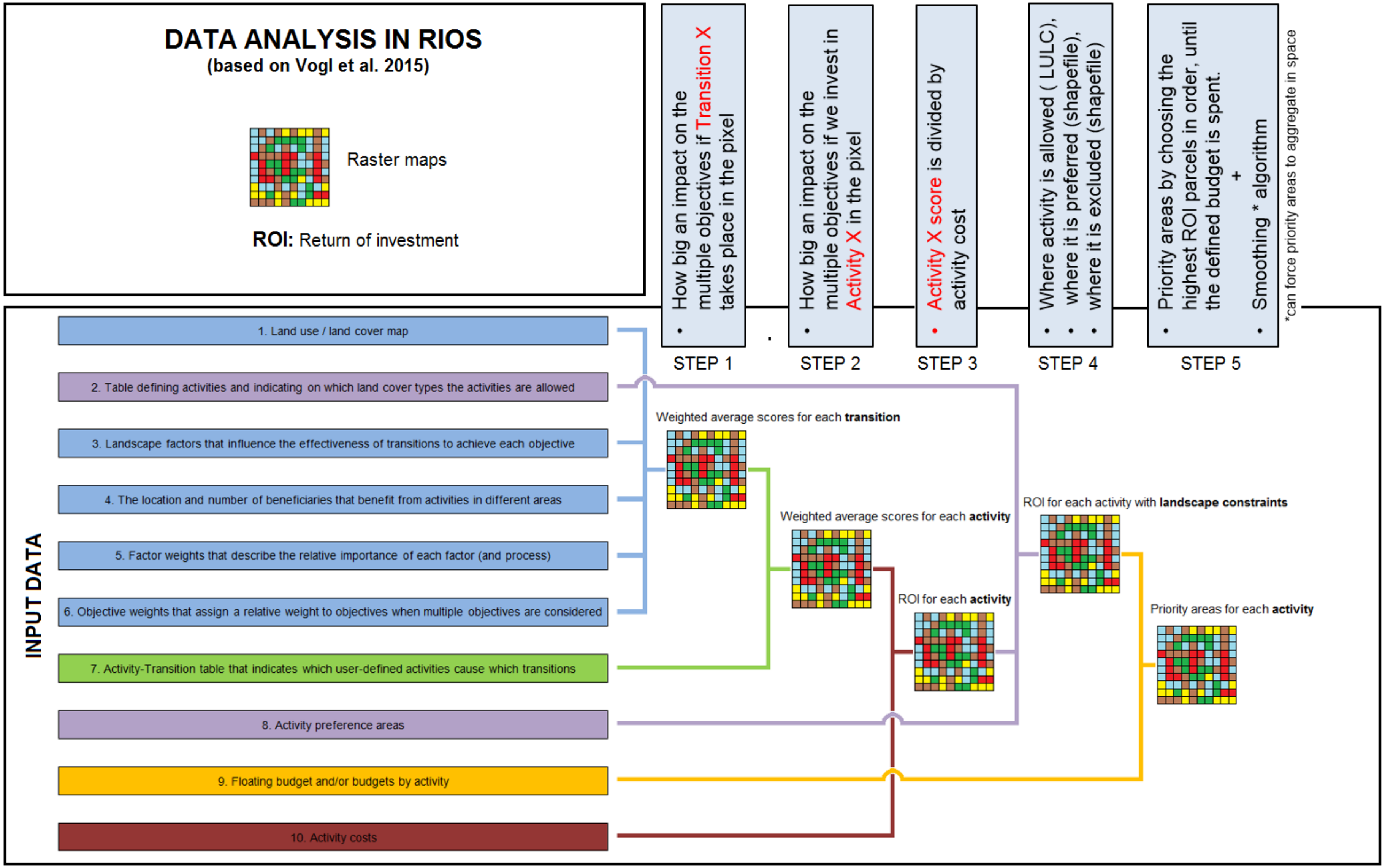
Shown below are the three modules of RIOS used in Chapter 4: "Investment Portfolio Advisor" for designing watershed investments (section 4.4.6.1); "Portfolio Translator" for generating future landuse scenario (section 4.4.6.2); and "Benefit Estimator" for modeling impact of selected ecosystem services (section for 4.4.6.3).



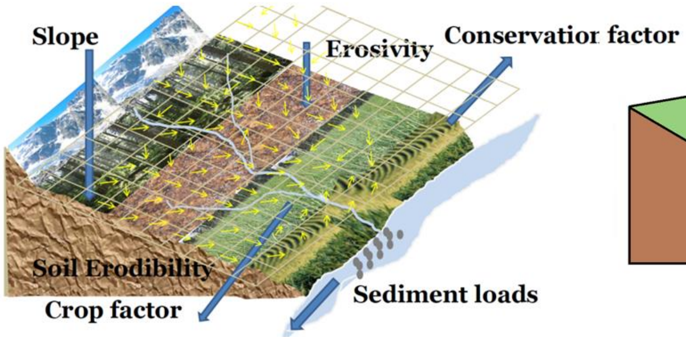
The input data for the RIOS Module "Investment Portfolio Advisor" are listed below:

1) Land use / land cover map;
2) Table defining activities and indicating on which land cover types the activities are allowed;
3) Landscape factors that influence the effectiveness of transitions to achieve each objective;
4) The location and number of beneficiaries that benefit from activities in different areas;
5) Factor weights that describe the relative importance of each factor (and process);
6) Objective weights that assign a relative weight to objectives when multiple objectives are considered;
7) Activity-Transition table that indicates which user-defined activities cause which transitions
8) Activity preference areas;
9) Floating budget and/or budgets by activity;
10) Activity costs.

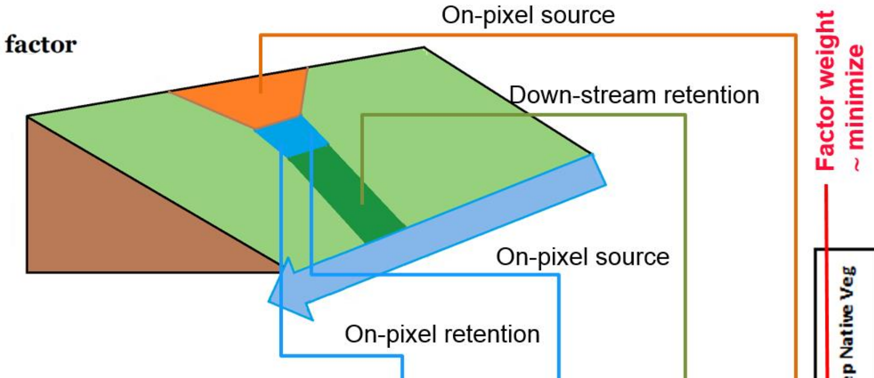
The diagram below shows how RIOS analyzes the 10 input data above.


DATA ANALYSIS IN RIOS
(based on Vogl et al. 2015)
Raster maps
ROI: Return of investment
How big an impact on the multiple objectives if Transition X takes place in the pixel
STEP 1
How big an impact on the multiple objectives if we invest in Activity X in the pixel
STEP 2
Activity X score is divided by activity cost
STEP 3
Where activity is allowed (LULC),
where it is preferred (shapefile),
where it is excluded (shapefile)
STEP 4
Priority areas by choosing the highest ROI parcels in order, until the defined budget is spent.
+
Smoothing * algorithm
STEP 5
*can force priority areas to aggregate in space
INPUT DATA
1. Land use / land cover map
2. Table defining activities and indicating on which land cover types the activities are allowed
3. Landscape factors that influence the effectiveness of transitions to achieve each objective
4. The location and number of beneficiaries that benefit from activities in different areas
5. Factor weights that describe the relative importance of each factor (and process)
6. Objective weights that assign a relative weight to objectives when multiple objectives are considered
7. Activity-Transition table that indicates which user-defined activities cause which transitions
8. Activity preference areas
9. Floating budget and/or budgets by activity
10. Activity costs
Weighted average scores for each transition
Weighted average scores for each activity
ROI for each activity
ROI for each activity with landscape constraints
Priority areas for each activity

The ranking method based on the USLE used in RIOS Investment Portfolio Advisor, taking into account the following factors: USLE C factor (“on-pixel source”), rainfall erosivity, soil erodibility, soil depth, on-pixel retention, riparian continuity, downslope retention index, upslope source index and beneficiaries.



(source: "InVEST 2.2.1 - Sediment retention model" by Yonas Ghile).



TRANSITIONS

Factor (Tool Inputs)	Process Captured	Keep Native Veg	Re-veg (Asst.)	Re-veg (Un-asst.)	Ag veg mgmt.	Ditching	Fert mgmt	Pasture mgmt
USLE C factor ("On-pixel source")	Source at pixel	~ 0.25	0.25	0.25	0.25	0.25	0.25	0.25
Rainfall erosivity	Source at pixel	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Soil erodibility	Source at pixel	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Soil depth	Source at pixel	0.25	0.25	0.25	0.25	0.25	0.25	0.25
On-pixel retention	Retention at pixel	0.5	~ 0.5	~ 0.5	~ 0.5	~ 0.5	~ 0.5	~ 0.5
Riparian continuity	Retention at pixel	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Downslope retention index	Retention downslope (want to minimize)	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1
Upslope source index	Upslope source area/ magnitude (want to maximize flow-on)	1	1	1	1	1	1	1
Beneficiaries	Location of beneficiaries relative to service provision	1	1	1	1	1	1	1